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North Carolina State Univ. at Raleigh

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COAL GASIFICATION/GAS CLEANUP TEST FACILITY: VOLUME V. PRELIMINARY ENVIRONMENTAL ASSESSMENT OF THE GASIFICATION AND GAS CLEANING OF NORTH CAROLINA PEAT

by

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16. ABSTRACT The report gives results from test runs at a small pilot-scale coal gasification and gas purification facility using North Carolina peat. Results from the peat gasification are compared with those obtained previously with a New Mexico subbituminous coal. The peat gas produced had slightly more CO and CO2, while the coal gas had slightly more methane. Production of gaseous sulfur species was much less for peat, due largely to the lower sulfur content of the peat itself. Wastewater analyses showed higher concentrations of phenols and other acidic compounds and lower concentrations of PNAs in the peat-derived wastewater than in the coal-derived wastewater. Peat char remaining after gasification was depeleted of As, Pb, and Hg to a greater extent than was the coal char. The peat itself contained a substantially higher Hg content than did the coal.

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Peat	Stationary Sources	21D
Gasification	Gas Cleaning	13H, 07A
Gas Scrubbing	Environmental Assessment	14B
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ABSTRACT

Five gasifier runs were completed successfully on the EPA gasifier-gas cleaning pilot plant facility using a feed of North Carolina peat. The first three of these runs made use of the gasifier and raw gas cleaning (PCS) system only, and were used to determine optimum operating conditions for the gasifier. The last two were integrated runs and made use of the full pilot plant facility, including the acid gas removal system. The peat used was obtained from First Colony Farms, Inc., from an operating site in Washington County, North Carolina. The peat was prepared for gasification by screening through 1/4 inch wire mesh and air drying to a moisture content of about 25% by spreading on the floor. The peat was fed to the gasifier without any further preparation.

The fluidized bed gasifier worked very well. With the top feed arrangement, most of the gas production took place in the zone above the fluidized bed by devolatilization; the gasifier acted as a two stage gasifier with a small fluidized bed of peat char in the lower zone and a devolatilization zone in the region above the bed.

Complete chemical analyses were made on all input, product, and effluent streams. Closed mass balances were obtained for total mass and for all major elements on both the gasifier-PCS system and the acid gas removal system (AGRS).

Areas of general environmental concern were the waste gas streams from the AGRS, the condensed organic compounds such as the tars and oils from the PCS system, and the waste water from the PCS system.

A general conclusion from this work is that the gasification of North Carolina peat produces a make gas very similar in character and composition to that from the gasification of a subbituminous coal, with the major differences being lower concentrations of sulfur compounds, due to the low sulfur content of the peat, and higher concentrations of the acidic organic compounds such as phenols.

A second conclusion is that the raw gas cleaning process, the PCS system in our facility, consisting of a cyclone separator, a venturi scrubber, filters, coolers, and demisters was effective in removing almost all of the nonvolatile compounds from the make gas stream. For all practical purposes, no hydrocarbons heavier than substituted benzenes entered the acid gas removal system. Those compounds which did accumulate in the chilled methanol

solvent would appear to be easily removed by distillation.

A final, general conclusion from this work is that North Carolina peat is an excellent feed material for steam-oxygen gasification, and its use as a gasifier feed presents no unusual problems. The product gas could be used as a low or medium Btu fuel gas with a minimum of gas cleaning, or could be upgraded to a high Btu gas by catalytic methanation. The product gas would also make an excellent feed stock for the production of a variety of chemicals by catalytic processes. In both of the latter cases, in addition to the raw gas cleaning, some form of acid gas removal system would have to be used prior to catalytic processing.

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FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz
	1 lb_m = 16 oz = 5 x 10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μ) = 10^{10} angstroms ($\AA$)
	= 39.37 in. = 3.2808 ft = 1.0936 yards = 0.0006214 mile
	1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 liters = 10^6 cm^3 = 10^6 ml
	= 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gallons
	= 1056.68 quarts
	1 ft^3 = 1728 $in.^3$ = 7.4805 gallons = 0.028317 m^3 = 28.317 liters
	= 28 317 cm^3
Force	1 N = 1 kg · m/s^2 = 10^5 dynes = 10^5 g · cm/s^2 = 0.22481 lb_f
	1 lb_f = 32.174 lb_m · ft/s^2 = 4.4482 N = 4.4482 x 10^5 dynes
Pressure	1 atm = 1.01325 x 10^5 N/m^2 (Pa) = 1.01325 bars
	= 1.01325 x 10^6 dynes/cm^2
	= 760 mm Hg @ 0°C(torr) = 10.333 m H_2O @ 4°C
	= 14.696 $lb_f/in.^2$ (psi) = 33.9 ft H_2O @ 4°C
	= 29.921 in Hg @ 0°C
Energy	1 J = 1 N · m = 10^7 ergs = 10^7 dyne x cm
	= 2.778 x 10^{-7} kW · hr = 0.23901 cal
	= 0.7376 ft-lb_f = 9.486 x 10^{-4} Btu
Power	1 W = 1 J/s = 0.23902 cal/s = 0.7376 ft · lb_f/s = 9.486 · 10^{-4} Btu/s
	= 1.341 x 10^{-3} hp

Example: The factor to convert grams to lb_m is 2.20462 lb_m/1000g

INTRODUCTION

As a part of a continuing research program on the environmental aspects of solid fuel conversion, the Department of Chemical Engineering at North Carolina State University carried out a brief test of the steam oxygen gasification and gas cleaning of North Carolina peat during the spring and summer of 1981. The work was sponsored jointly by the North Carolina Energy Institute, the Carolina Power and Light Company, and the U. S. Environmental Protection Agency. The facility, to be described later, was constructed in 1977-78 under the sponsorship of the EPA.

The overall objective of the peat gasification project was to characterize the gaseous and condensed phase emissions from the gasification-gas cleaning process, and to determine how emission rates of various pollutants depend on adjustable process parameters. The detailed objectives for the set of exploratory runs using North Carolina peat as the feed material were:

1. To test the feasibility of the steam-oxygen gasification of peat in a fluidized bed gasifier.

2. To evaluate the product gas from the gasifier-PCS system and to make a preliminary evaluation of the product gas quality.

3. With the gasifier-gas cleaning system operating as an integrated facility, to sample and analyze all feed and effluent streams in sufficient detail to make a complete environmental assessment of peat gasification.

4. To evaluate the effectiveness and the necessity of an acid gas removal system for peat gasification.

The facility used for this research was a small coal gasification-gas cleaning pilot plant. A complete description of the facility and operating procedures is given by Ferrell et al., Vol. I, (1980), and in abbreviated form by Felder et al. (1980). A schematic diagram of the Gasifier, the Acid Gas Removal System (AGRS), and other major components is shown in Figure 1, and a brief description of the facility is given in a later section of this report.

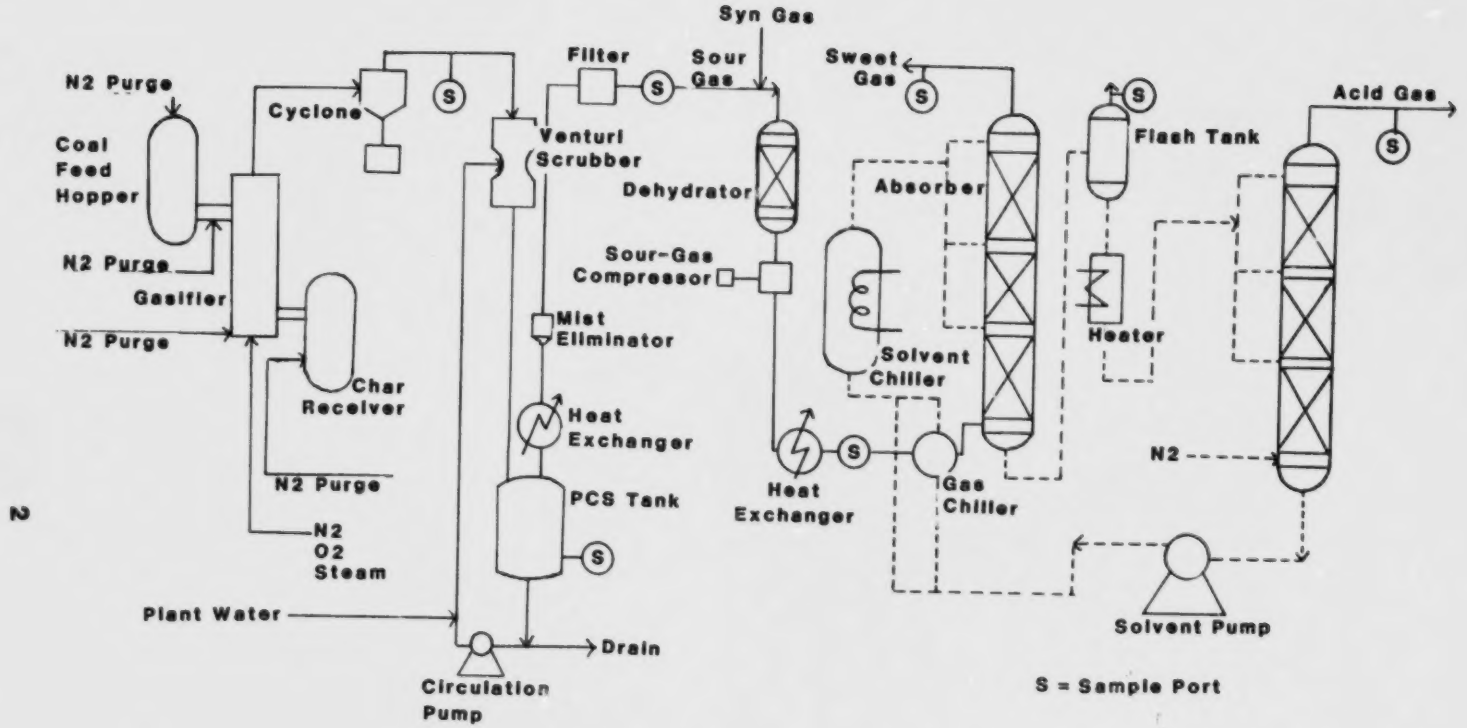


Figure 1

Pilot Plant Facility

Prior to this study, a pretreated Western Kentucky No. 11 coal was gasified with steam and oxygen, followed by a detailed study of the steam-oxygen gasification and gas cleaning using a New Mexico subbituminous coal. Full reports on these systems have either been issued or are in preparation (Ferrell et al., Vol. II, 1981, and Ferell et al., Vol. III, 1982).

This report concerns the third major study carried out on the facility, the steam-oxygen gasification of North Carolina peat using refrigerated methanol as the AGRS solvent. The peat was obtained from the First Colony Farms, Inc. as milled peat, was screened to pass through a 1/4 inch screen, air dried, and gasified without further treatment. Table 1 shows an average analysis of the char, the subbituminous coal, and the peat used in these studies.

Very little experimental work on the steam-oxygen gasification of peat has been done in the United States. The Institute of Gas Technology carried out an experimental program on hydrogasification of peat in a two stage gasifier, with some tests of direct fluidized bed steam-oxygen gasification (IGT 1978). North Carolina peat was included in the feed materials used. A state-of-the-art review was presented by Punwani (1980), and has been published by the Institute of Gas Technology.

This report presents a brief description of the facility, a summary of the gasifier operation using North Carolina peat, the results of detailed chemical analyses of gasifier effluent streams, and the results of the operation of the AGRS using the gasifier make gas as feed.

TABLE 1
COAL, CHAR, AND PEAT ANALYSIS

	Coal Char Wt %	New Mexico Coal Wt %	North Carolina Peat Wt %
Proximate Analysis			
Fixed Carbon	86.0	35.2	26.3
Volatile Matter	2.4	31.7	46.3
Moisture	0.9	10.5	22.8
Ash	10.7	22.6	4.6
Ultimate Analysis			
Carbon	83.8	52.5	45.9
Hydrogen	0.6	4.8	4.3
Oxygen	2.2	18.3	44.1
Nitrogen	0.1	1.2	0.9
Sulfur	2.6	0.6	0.2
Ash	10.7	22.6	4.6

THE FACILITY

The pilot plant facility is a small but complete coal gasification - gas cleaning plant. The plant is capable of achieving long periods of steady operation, and can therefore produce a full set of product and effluent streams under known and steady conditions. Measurement of flow rates and compositions of these streams under such conditions gives a true measure of product gas composition and production rates, and a good evaluation of environmental problems.

The principal components of the pilot plant are a continuous fluidized bed gasifier, a cyclone separator, a venturi scrubber, and an acid gas removal system. A process control and data acquisition system for operation, data logging, and display is also used. Each of these systems is described briefly in the following sections:

THE GASIFIER

The gasifier is a fluidized bed reactor consisting of a 15.2 cm (6 in) I.D. Schedule 40 pipe (316 SS) enclosed in several layers of insulation and contained in a 61 cm (24 in) I.D. Schedule 80 carbon steel pipe. The overall height of the reactor is about 3.7 m (12 feet) of which 3 feet is used as a reaction zone. Three triangularly arranged nozzles are used to feed steam, nitrogen, and oxygen into the reactor which normally operates at 790 kPa (100 psig). Thermocouples are mounted in the center of the bed above the gas distributing nozzles to monitor the bed temperature profile.

Coal, or peat, is fed and spent char is removed from the reactor by screw conveyors from pressurized hoppers at either end of the reactor. A nuclear level gauge is used to monitor the fluidized bed height, which is controlled by adjusting the char removal rate. The operating temperature normally ranges from 870 to 1040 ^{o}C (1600 to 1900 ^{o}F).

THE PCS SYSTEM

Gas exiting the gasifier contains particulates, tars, and heavy oils as well as several water-soluble compounds which are removed in the PCS (particulates, condensables, and solubles) system. A cyclone separator collects entrained particulates and a venturi scrubber is used to quench the gas to remove condensables and water-soluble compounds. Heat exchangers reduce the temperature of the quenched gas stream to near room temperature.

Either fresh city water or water recycled from the scrub water (PCS) tank can be fed to the venturi scrubber. Finally, a mist eliminator, a series of filters, and a dehydrator remove the last traces of particulates and water before the gas is fed to the acid gas removal system.

A Western Kentucky No. 11 coal char, containing only trace amounts of volatile matter, was gasified in the early stages of operation. The gas produced from this feedstock was relatively free of tars and oils. Initial work with the higher volatile matter New Mexico sub-bituminous coal led to the production of considerable amounts of tar and forced the shutdown of operation due to line pluggage.

The PCS system was reconstructed by increasing the size of the line leaving the gasifier from one inch to three inches in diameter. The venturi scrubber was replaced with a series of spray nozzles at the inlet of the scrub water tank. At this point in the system the pipe size is reduced from three inches to one inch to promote better gas-liquid contacting. A heat exchanger, used previously to cool the gases downstream of the venturi scrubber, was removed and cooling coils were installed inside the scrub water tank to keep the water temperature well below the boiling point. A water separator was also installed downstream of the outlet heat exchanger to remove any entrained water in the exiting gas stream. In addition, the top of the gasifier reactor vessel was rebuilt to enlarge the coal feed and the gas exit lines.

The modified system functioned well during the gasification of the New Mexico subbituminous coal, was satisfactory for the gasification of North Carolina peat, and was able to provide a clean, dry gas to the acid gas removal system.

THE ACID GAS REMOVAL SYSTEM

The major purpose of the acid gas removal system (AGRS) is to remove carbon dioxide and hydrogen sulfide from the product gas stream. In so doing it also usually removes the other sulfur gases and many of the hydrocarbons of molecular weight higher than methane.

The acid gas removal system used in this study is modular in design so that alternative absorption processes can be evaluated. The system was designed to operate with four different solvents: refrigerated methanol, hot potassium carbonate, monoethanolamine, and the dimethyl ether of polyethylene glycol. With minor modifications, other solvents could also be used. Refrigerated methanol has been used so far in this study.

The major components of the AGRS are an absorption column, a flash tank, and a stripping column with the necessary auxiliary equipment. Gases from either the gasifier or gas cylinders are fed to the system through a pair of dehydrating towers containing molecular sieves. The gases are compressed to a pressure ranging from 1825-3200 kPa (250-525 psig) in a two-stage compressor and then cooled to remove the heat of compression. These gases

are cooled further in a chiller by exchange with cold solvent leaving the stripper bottom. They are then fed to the absorber at a point just below the packing support to minimize end effects.

The absorption column contains three 2.2 m (7.1 ft) sections of 6.4 mm (1/4") ceramic Intalox saddle packing. The column is well-insulated and approaches adiabatic operation. Solvent which is cooled in a refrigeration unit can be fed to the absorber at the top of the first, second, or third packed section. This provides flexibility in mass transfer studies.

The solvent exiting the absorber is fed to a flash tank where some of the absorbed gases are released. The solvent then exchanges heat with the solvent exiting the stripper and is fed to the stripper. The stripper is similar to the absorber in design in that it contains three packed sections of ceramic Intalox saddles, any or all of which sections can be used in mass transfer studies. The column approaches adiabatic operation, and the solvent can be regenerated either by stripping with an inert gas or with the reboiled methanol vapors.

For more carefully controlled mass transfer studies, a synthetic gas feed stream (SYNGAS) can be prepared at a mixing manifold. Any or all of the gases produced in the gasifier can be fed to the AGRS. Most of the SYNGAS runs made prior to this study used a mixture of nitrogen and carbon dioxide as the feed gas to evaluate packing characteristics and to determine the heat of solution of carbon dioxide in methanol.

PROCESS CONTROL AND DATA ACQUISITION SYSTEM

Approximately 100 process sensors are used to obtain information during pilot plant operation. The plant is controlled with a Honeywell TDC 2000 process control computer which has a capability of regulating 16 process control loops throughout the pilot plant. Also, an alarm system incorporating all process sensors calls attention to process problems by sounding an audible alarm and lighting an alarm light on a process schematic above the control panel. The alarm system can also be set to cause plant shutdown automatically for pre-set alarm points.

The 100 process sensors (temperatures, pressures, differential pressures, flow rates, and levels) are monitored through a data acquisition system linked to a PDP 11/34 minicomputer. Each sensor is interpreted every five seconds for display on a video terminal. The information is averaged and stored every five minutes on magnetic disk for future data reduction. The capability to plot information from each process sensor for the previous hour on a video or hard-copy terminal during the run also exists. Strip chart recorders are used for continuous monitoring of process temperatures and selected process variables.

The data acquisition computer system is also used for all data reduction calculations and is programmed to produce output results in a form suitable for reports. Examples are given later in this report.

DESCRIPTION OF PROCESS STREAMS AND SAMPLING PROCEDURES

This section presents a brief description of the various feed, effluent, and process streams, and how they were metered, controlled, sampled, and analyzed. Most of the input and output stream sample points are shown on Figure 1. The sample train, mentioned frequently in the sections that follow, is located just downstream of the cyclone.

INPUT STREAMS

Peat Feed

Multiple samples of the feed peat were taken before each run, subjected to proximate and ultimate analyses, and analyzed for several trace elements. The analytical methods used for trace metal analysis will be described later in this report.

The peat feed stream was metered into the reactor by controlling the rate of revolution of the feed screw. The quantity of peat delivered per revolution of the screw was remarkably constant for these runs, and thus the feed rate during the steady state portion of a run could be determined accurately.

Gas Feeds

Gasifier Feed--

The oxygen feed was from a bank of six cylinders; the nitrogen feed was from a six-thousand gallon liquid nitrogen tank with an atmospheric vaporizer; and the steam feed was from a high pressure building process steam line. All feed streams were preheated and metered, and were controlled by the process control computer system. The calibrations of the flow elements and transmitters were checked frequently during this experimental program.

AGRS Feed--

The gas feed to the AGRS is normally either a mixture of gases from cylinders or the gasifier make gas. For all runs discussed here it was gasifier make gas and was passed through a dehydration tower packed with molecular sieves, compressed to approximately 35 atm, and cooled to ambient temperature. The desired flow rate to the absorber was controlled and measured by an orifice meter, calibrated at operating pressure.

OUTPUT STREAMS

Spent Char

Multiple samples were taken from the char receiver vessel or from the bottom of the reactor after a run. For some runs, especially when the carbon conversion was high and very little spent char was formed, difficulty was experienced in obtaining a reliable sample representing the steady state portion of a run. Analyses were essentially identical to those for the feed peat. The steady state char removal rate was determined from the total char removed, the total revolutions of the removal screw, and the rate of revolution of the screw during the steady state. Char removal rates were very difficult to determine, since during the steady state portion of a run, the removal rate was very low, and the performance of the removal screw was very erratic.

Cyclone Fines

Samples were collected from the cyclone solids collection tank. Since the cyclone fines were sometimes wet, it is possible that some condensation on the fines occurred during or after shutdown. In addition, for several of the runs, very little solids were collected in the cyclone. For these reasons cyclone solids analyses were generally less reliable then for the other solids. Analytical methods were the same as those for the feed coal.

Condensed Phases After Venturi Scrubber (PCS Tank)

After shutdown, samples of particulates, tar, and water were taken from the PCS tank. For all runs reported on here, the venturi scrubber water was recirculated from the tank to the spray nozzles, and thus contains material from the startup, steady state, and shutdown periods. Prior to each run, the tank was filled with approximately 160 gallons of fresh water, and thus the final composition of the water depended on the length of the run. Methods of analysis and results are presented later in this report.

Gas Samples

Gas samples were taken from the six locations noted on Figure 1 at operating pressure using one liter stainless steel bombs, and at lower pressures using one liter glass bombs. The glass bombs were coated internally with hexamethyldisilizane to reduce the adsorption of trace sulfur, nitrogen and hydrocarbon species. For the purposes of sampling, the steady state period was determined by the stability of various temperatures, pressures, flow rates, and levels over long periods of time. Examples of plots of several critical process variables versus time are given in a later section of this report. Times at which samples were taken for the run shown are noted on the plots.

Gas Samples from the PCS System--

Gases from the PCS system were metered and sampled after the final filter and before the dehydrators. Samples were collected at high pressure in stainless steel bombs, and at a lower pressure (approximately 20 psig) in glass bombs for later analysis by gas chromatography. Analysis methods and results are presented later.

The reactor make gas flow meter-transmitter calibration was checked frequently, and the mass flow rate indicated by the data acquisition system was corrected for gas composition before being used for mass balances.

Gas Samples from the AGRS--

The gas sampling locations used for the AGRS are shown in Figure 1, and samples were taken as described above.

The flow meter-transmitter calibrations at the absorber, flash tank, and stripper were checked frequently, and the mass flow rates indicated by the data acquisition system were corrected for gas composition before being used for mass balances.

Liquids

Water samples were taken from the PCS tank and the sample train and will be discussed in some detail in a later section of this report.

After the reactor make gases leave the PCS system, they are passed through a bed of molecular seives to remove remaining traces of moisture. They are then compressed to approximately 35 atm, cooled to about $10^{o}C$, and then passed through a knockout drum to eliminate flow pulsations and to collect any condensed liquid. Under the conditions of the runs described here, a substantial amount of condensed liquid was collected. Samples were taken and were analyzed by GC/MS.

In the AGRS, liquid samples were taken at the exit line from the absorber, flash tank, and stripper at system pressure. These samples were then vaporized and injected into a gas chromatograph for analysis. Attempts to take samples from the column packing were unsuccessful due to problems of liquid entrainment and flashing.

In addition, liquid methanol samples were taken at the stripper exit at the end of each integrated run for GC/MS analysis.

Sample Train

In addition to the normal effluent streams, a small side stream was drawn off just downstream of the cyclone and passed through a sample train. A schematic diagram of the sample train is shown in Figure 2. For mass balances, the gas flow through the sample train was added to that metered at the PCS system outlet. During steady state operation, the gas flow through the sample train was metered with a test meter, and the water condensed in

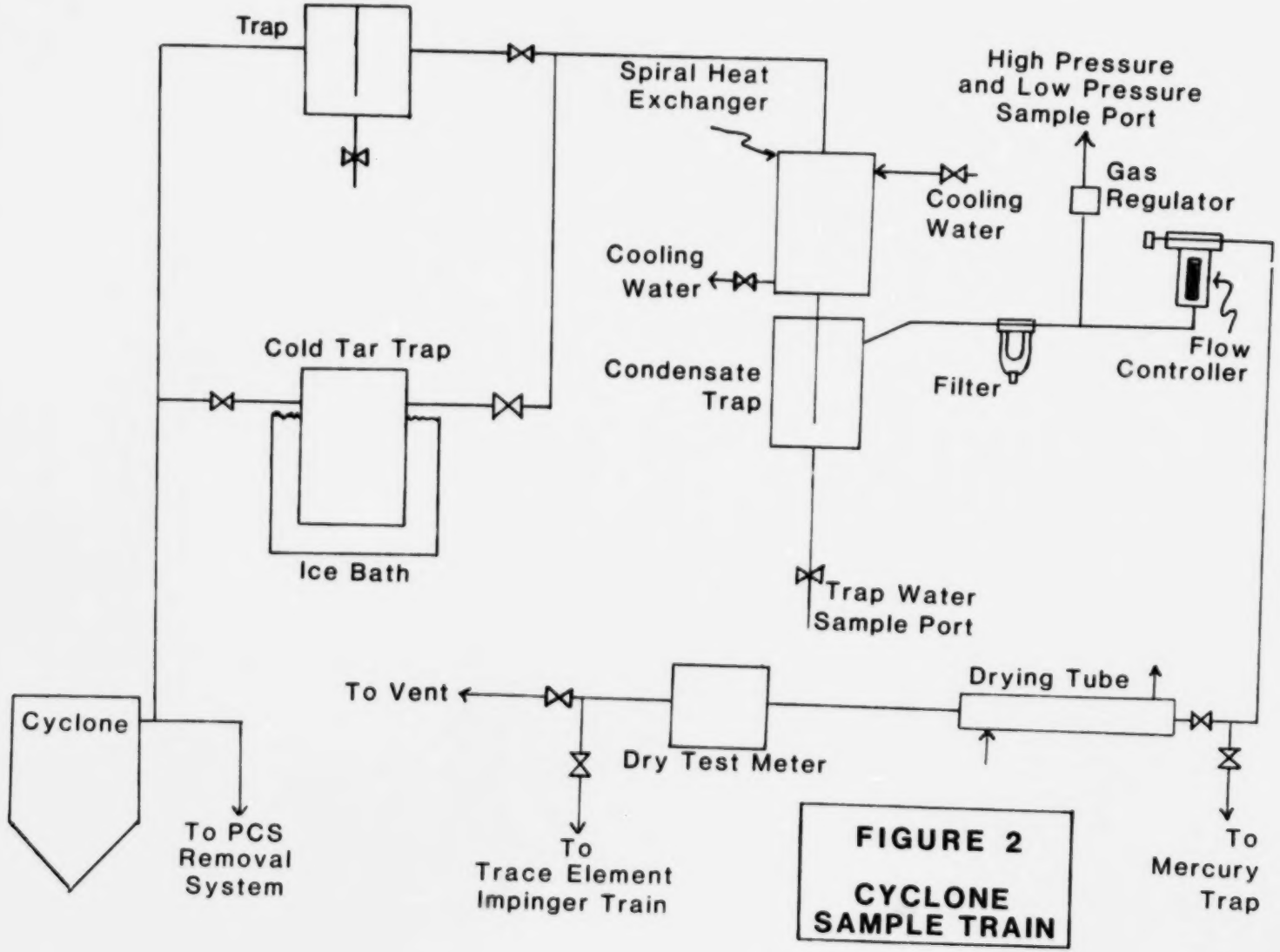


FIGURE 2

CYCLONE SAMPLE TRAIN

the train was measured and used as the primary measurement of the water content of the reactor make gas. Gas samples were taken in both stainless steel and glass bombs for GC analysis.

For the first two gasifier runs using peat, frequent gas samples were taken at the sample train and were analyzed immediately on the Carle gas chromatograph. Since the objective of these first runs was to find an optimum set of gasifier operating conditions for subsequent integrated runs, conditions were changed frequently, and the consequences of these changes were followed by gas analysis.

The gas sample train was designed to allow representative samples of particulates, tars, and condensed liquids to be taken. It was also necessary, especially in the case of trace element analysis, to trap all of the particulates, tars, and condensed liquids in one location to minimize sample contamination. For this purpose, a cold trap, which consisted of a vertical stainless steel cylinder, equipped with gas inlet and exit ports, and a drain-plug to drain the condensed liquids, was installed in the sample train. The cylinder was loosely packed with stainless steel wool, which trapped the particulates and tars as the gas travelled through it. The entire trap was immersed in an ice bath. The liquid collected at the bottom of the cylinder was drained at the end of the run. When the gasifier reached steady-state, the cold trap was opened and the sample-train gas was diverted through it for one hour. At the end of the run, the contents of the trap were separated into solid, tar, and liquid fractions, and sent for analysis.

ANALYTICAL PROCEDURES

SOLIDS

Both proximate and ultimate analyses were performed on all solid input and output streams. The proximate analyses were performed using a Fisher Coal Analyzer Model 490. A Lindberg Combustion Furnace Model 123-SP was used to determine carbon and hydrogen for the ultimate analyses, and a Fisher Sulfur Analyzer Model 470 was used for sulfur analysis. Nitrogen was determined by the Kjeldahl-Gunning method, and oxygen was determined by difference. Certified coal standards were analyzed periodically to check the accuracy of all analyses.

LIQUIDS

The methods used for the routine analysis of the waste water, both the water from the PCS tank and from the sample train, are listed below:

1. Ammonia - Acidimetric method 418D (Franson 1975). The sample pH is adjusted, it is distilled into boric acid, and then titrated with 0.1N H_2SO_4.

2. Cyanate - Pretreatment and heating by method 413J (Franson 1975), distillation and titration by method 418 (Franson 1975).

3. Carbon, TOC and TVC (Total organic carbon and total volatile carbon) - Samples were analyzed by a Dohrmann Envirotech Organic Carbon Analyzer. Samples were preserved by adjusting the pH to 2.0 with HCl. Thirty uL injections of the sample and KHP standards were used.

4. Chloride, Fluoride, Sulfate, Sulfite - Analysis was by a Dionex System 10 Ion Chromatograph. Identification was by retention time comparison with standards. Concentrations were determined by calibration curves (micro-moles versus peak height) of standards.

5. COD (Chemical oxygen demand) - Analysis was by the Hach COD System, a compact system in which the dichromate reflux takes place in a small sealed vial. A titration determines the unreacted dichromate, and gives an estimate of the biological oxygen demand (BOD).

6. Nitrogen - Samples were analyzed by method 421 (Franson 1975). The sample was digested to convert the organic nitrogen to ammonia (Kjeldahl), then distilled and titrated as in ammonia determination.

7. pH - Samples were determined by an Orion Microprocessor Ionalyzer 901. Calibration was with Fisher buffer solutions, and pH was determined with an Orion combination electrode.

8. Phenols - Analysis was by method 510c(Franson 1975). Phenols were reacted with 4-aminoantipyrine at pH 10 in the presence of potassium ferricyanide to form a colored antipyrine dye. The color was measured spectrometrically at 510 nm and plotted against standards.

9. Thiocyanate - Analysis was by method 413k(Franson 1975). The ferric ion was reacted with thiocyanate at acid pH to give an intense red color which could be read spectrometrically at 480 nm and plotted against standards.

In addition to the standard liquid analyses described above, samples of the water from the PCS tank and from the sample train, a sample of condensed liquid from the reactor make gas (knockout drum sample), samples of the methanol solvent from the stripper exit taken at the end of an integrated run, and samples of tar from the cold trap, were prepared and analyzed as described below:

GOP-4B Sample Train (Base/Neutral Extract)

Sample Collection:

The condensed phases from the sample train consist of everything which will condense when the gas stream is cooled to about 20°C. Samples of water from the sample train condensate were collected during the steady state portion of a run.

Sample Preparation and Analysis:

The base/neutral extract was prepared according to an adaptation of EPA Method 610 as it appears in the Federal Register, December, 1979. This method was altered to employ a Waters Inc. Sep-Pak Cartridge in place of a liquid-liquid extraction, silica gel column for sample cleanup. The sample train water was filtered and passed through an activated C_{18} Sep-Pak. The organic compounds were then eluted from the Sep-Pak with cyclohexane. The extract was passed through a silica Sep-Pak, eluted with pentane, and then with a 40/60 mixture of methylene chloride/pentane. The 40/60 extract was analyzed by GC/MS, programmed to run from 25°C-250°C at 5°C/min.

GOP-6 PCS Water (Base/Neutral and Acid Extract)

Sample Collection:

Samples of the PCS water were collected from the PCS tank after the completion of run GOP-6.

Sample Preparation and Analysis:

The PCS tank water was extracted to obtain both a base/neutral and an acid extract for analysis. The sample was prepared in accordance with the methods specified in "Sampling and Analysis Procedures for Screening of Industrial Effluents", U. S. EPA., Cincinnati, Ohio, 45268, March, 1977, revised April, 1977.

One liter of PCS water was filtered, the pH was adjusted to over 10 with NaOH, and was then extracted with methylene chloride. This provided the base/neutral extract which was concentrated to 2 ml. This extract was analyzed by GC/MS programmed to run from 25°C to 250°C and 2°C/min.

The remaining water sample was pH adjusted to pH < 2 with H_2SO_4 and extracted with methylene chloride. This provided the acid extract which was concentrated to 2 ml and analyzed by GC/MS, programmed to run from 30°C to 250°C at 2°C/min.

Compressor Knock-out for Combined Peat Runs (GOP-1 through GOP-6)

Sample Collection:

The compressor knock-out sample was collected from a knock-out drum downstream from the sour gas compressor and gas cooler. It consisted of the components of the gasifier make gas which were still in the vapor phase after passing through the PCS subsystem, but were sufficiently non-volatile to condense at the reduced temperature and increased pressure existing at the knockout drum.

Sample Preparation and Analysis:

A volume of approximately 500 ml was collected from the knockout drum. The sample was passed through a bed of anhydrous sodium sulfate to remove any traces of water in the sample. The dried sample was analyzed by the GC/MS without further preparation. The GC/MS was programmed to run from -30°C to 170°C at 2°C/min to separate the most volatile components.

GOP-4B Stripper Exit Methanol

Sample Collection:

This sample consisted of the methanol solvent from the AGRS, collected at the exit of the stripper column at the completion of the run.

Sample Preparation and Analysis:

Approximately one liter of the methanol was passed through a bed of anhydrous sodium sulfate to remove any traces of water. The sample was then evaporated in a rotary evaporator over a water bath to dryness, and then brought to a volume of approximately 2 ml with methylene chloride. The sample was analyzed by GC/MS, programmed to run from 30°C to 250°C at 5°C/min.

All samples mentioned above were analyzed by a Hewlett Packard model 5985B GC/MS at the following conditions:

Column:	25m x 0.25 mm, glass, coated with SP-2100
Carrier:	Helium
Flow rate:	1 ml/min
Source temp:	200°C
Electron energy:	70 mV
Scan Rate:	40-450 amu
Scan Length:	1.3 seconds

The stripper exit methanol sample was also analyzed by high pressure liquid chromatography (HPLC) without any preparation other than filtering. This analysis was carried out on a Waters Inc. chromatograph by reverse-phase using a methanol-water gradient program.

In addition to the liquid analyses described above, the Research Triangle Institute carried out a capillary GC analysis of the tar collected from the steady state portion of GOP-4B. A sample of this tar was also analyzed by GC/MS on the N. C. State University facility.

GASES

Gas Analysis Methods

Hydrogen, nitrogen, oxygen, carbon monoxide, carbon dioxide, methane, ethane, ethylene, and hydrogen sulfide (in relatively high concentrations) were analyzed on a Carle Series SX AGC-111H gas chromatograph in conjunction with a Perkin-Elmer Sigma 10 Chromatography Data System. The AGC-111H is a dual valve, dual column, dual detector unit. Gases were injected through the first valve, which could also be switched for a column backflush. A second valve is located between the two columns and switches to align them in series or bypass flow to the second column. The first column is 6′ x 1/8" 80% Poropak N and 20% Poropak Q. The second column is 7′ x 1/4" Molecular Sieve 13X. A third column, 8% OV101 Chromasorb WAWDMCS, is used as a reference column. Columns were maintained at 75°C throughout the analyses.

Detection of all the above mentioned gases except hydrogen was performed with a thermal conductivity (TC) detector with helium carrier gas. Hydrogen was separated from the other gases by permeation through a palladium-tube transfer system. A second TC detector, using nitrogen carrier gas, detected H_2 at concentrations from 0.03% to 100%. The currents in both detectors were set at 20 mA. The Perkin-Elmer Sigma 10 Chromatography Data System performed automated valve switching and peak area integration. An example of a chromatogram from the Carle-Sigma 10 for the 12:30 gas sample taken at the PCS exit for run GOP-6 is shown in Figure 3.

Hydrogen sulfide, carbonyl sulfide, methyl mercaptan, ethyl mercaptan, carbon disulfide, and thiophene were analyzed on a Varian gas chromatograph. A gas sampling valve was added for sample injection. Sample components were separated on a 6′ x 1/8" teflon 1.5% x E-60, 1% H_3PO_4 Carbopak B column which was temperature programmed. The column was held at 25°C for 3 minutes, heated to 130°C at 15°C per minute, and held at 130°C for 6 minutes.

Detection of sulfur gases in the presence of high hydrocarbon concentrations was accomplished using a Varian dual-flame flame photometric detector. The detector was heated to 180°C and used helium as carrier gas and hydrogen and air as flame gases. An example of a chromatogram of the PCS gas sample taken at 12:30 for GOP-6 is shown in Figure 4.

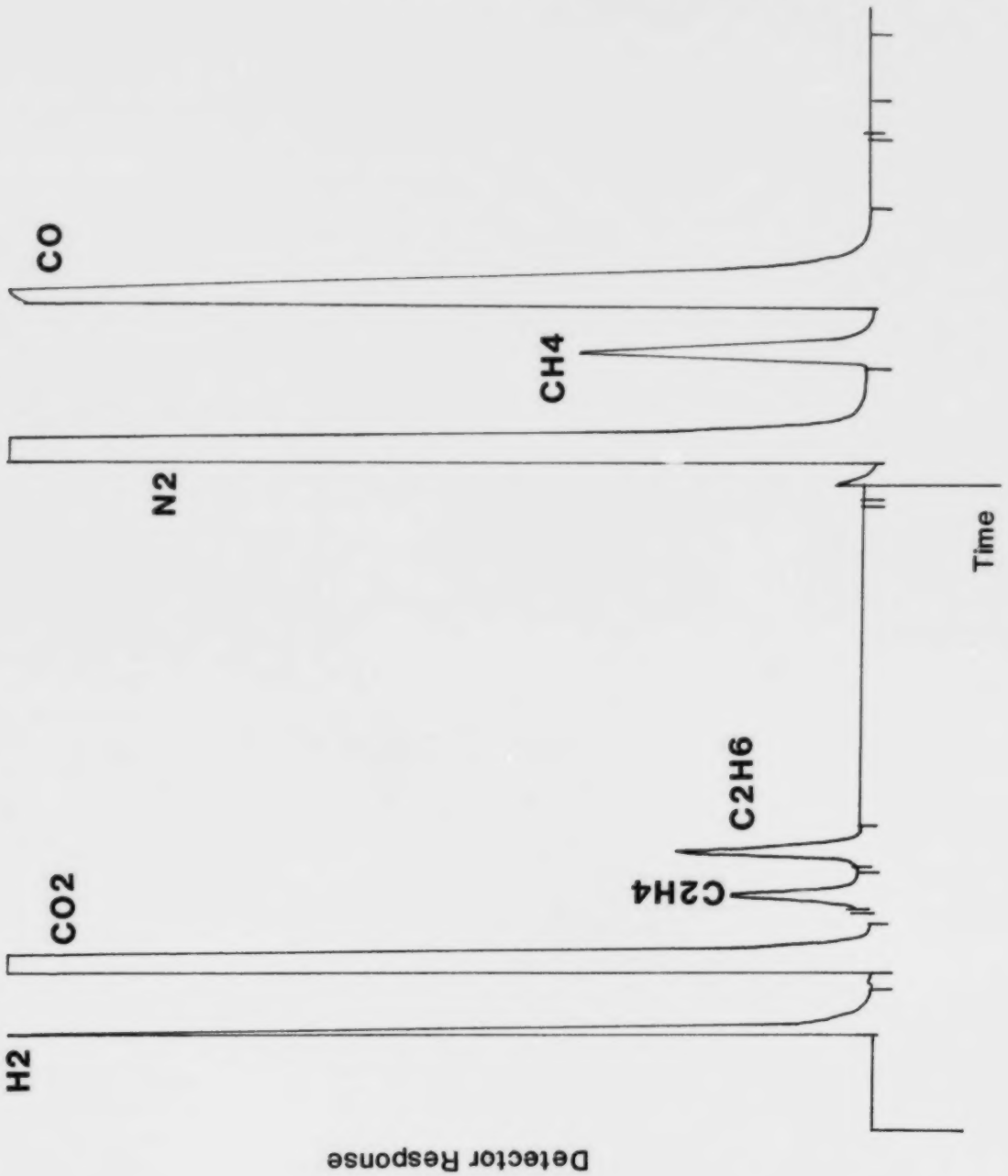
Ethane, ethylene, all C3 and C4 hydrocarbons, and methanol were analyzed on a Tracor 550 gas chromatograph. A gas sampling valve and valve oven were added for sample injection. The sample components were separated on an 8′ x 1/8" stainless steel Poropak Q column in series with an 10" x 1/8" stainless steel 20% Carbowax 20M TPA column. The columns were temperature programmed from 50°C to 200°C at 8°C per minute. The gases were detected by a flame ionization detector heated to 250°C. Helium was used as the carrier gas. A sample chromatogram of the PCS gas sample taken at 12:30 for GOP-6 is shown in Figure 5.

Benzene and toluene were analyzed on a Tracor 550 gas chromatograph with a heated gas sampling valve for injection. A 7′ x 1/8" stainless steel 35% BC 150 Chromasorb PAW, DMCS column separated benzene and toluene. The column was temperature programmed from 120°C to 200°C at 8°C per minute. Components were detected by a flame ionization detector heated to 250°C. Helium was used as the carrier gas. A chromatogram is shown in Figure 6.

For all the gas chromatographic analyses, the Perkin-Elmer Sigma 10 Chromatography Data Station received all detector outputs and integrated to calculate peak areas. The peak areas were converted to micromoles and mole % by external standard calibration curves in a series of steps using a Hewlett Packard 97 programmable calculator and the SAS statistical program. Final compilation and storage of data was accomplished by means of the GASS computer program described below.

Figure 3

EXAMPLE CHROMATOGRAM FROM GOP-6



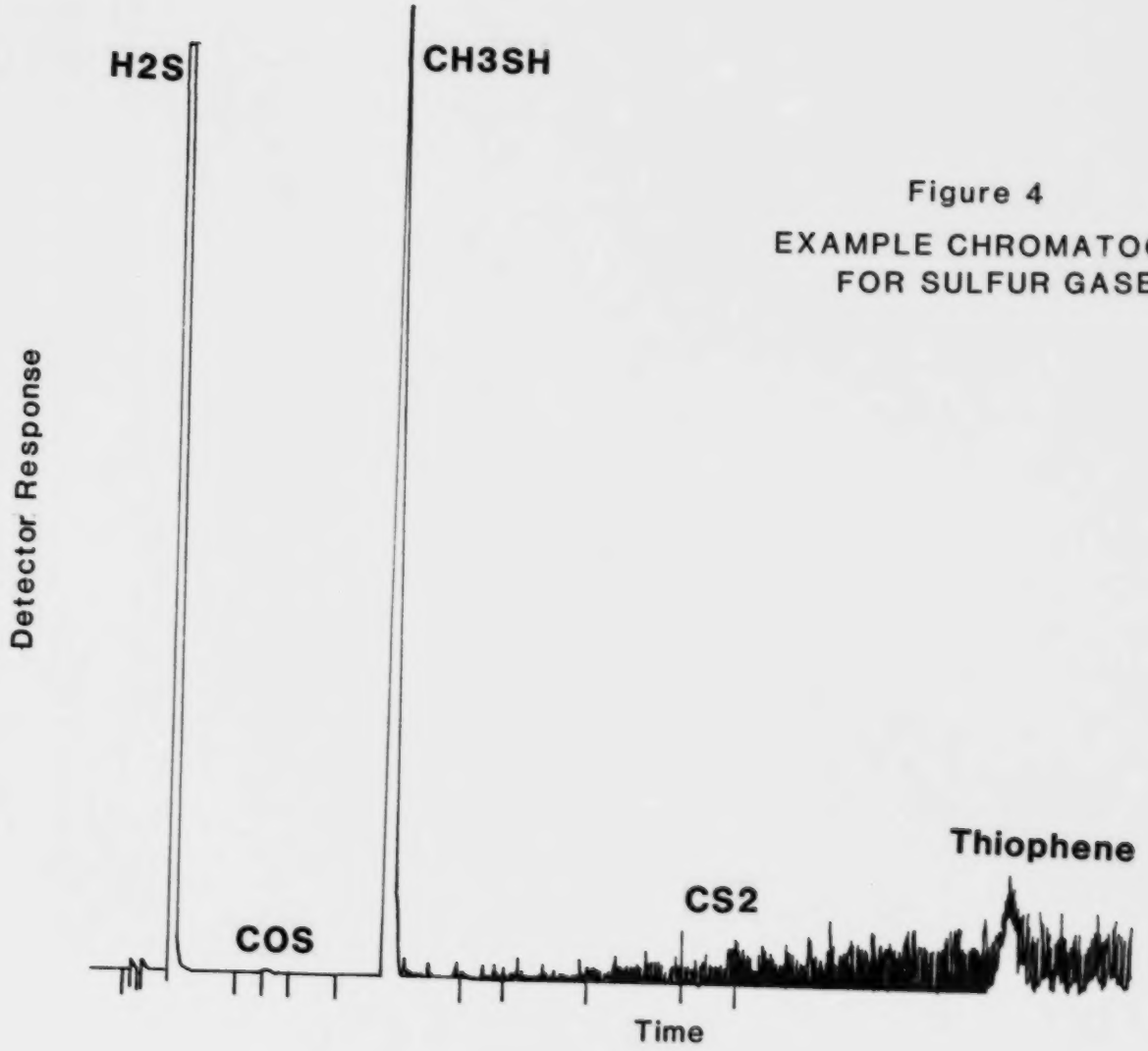


Figure 4

EXAMPLE CHROMATOGRAM
FOR SULFUR GASES

Figure 5

EXAMPLE CHROMATOGRAM
FOR HYDROCARBONS

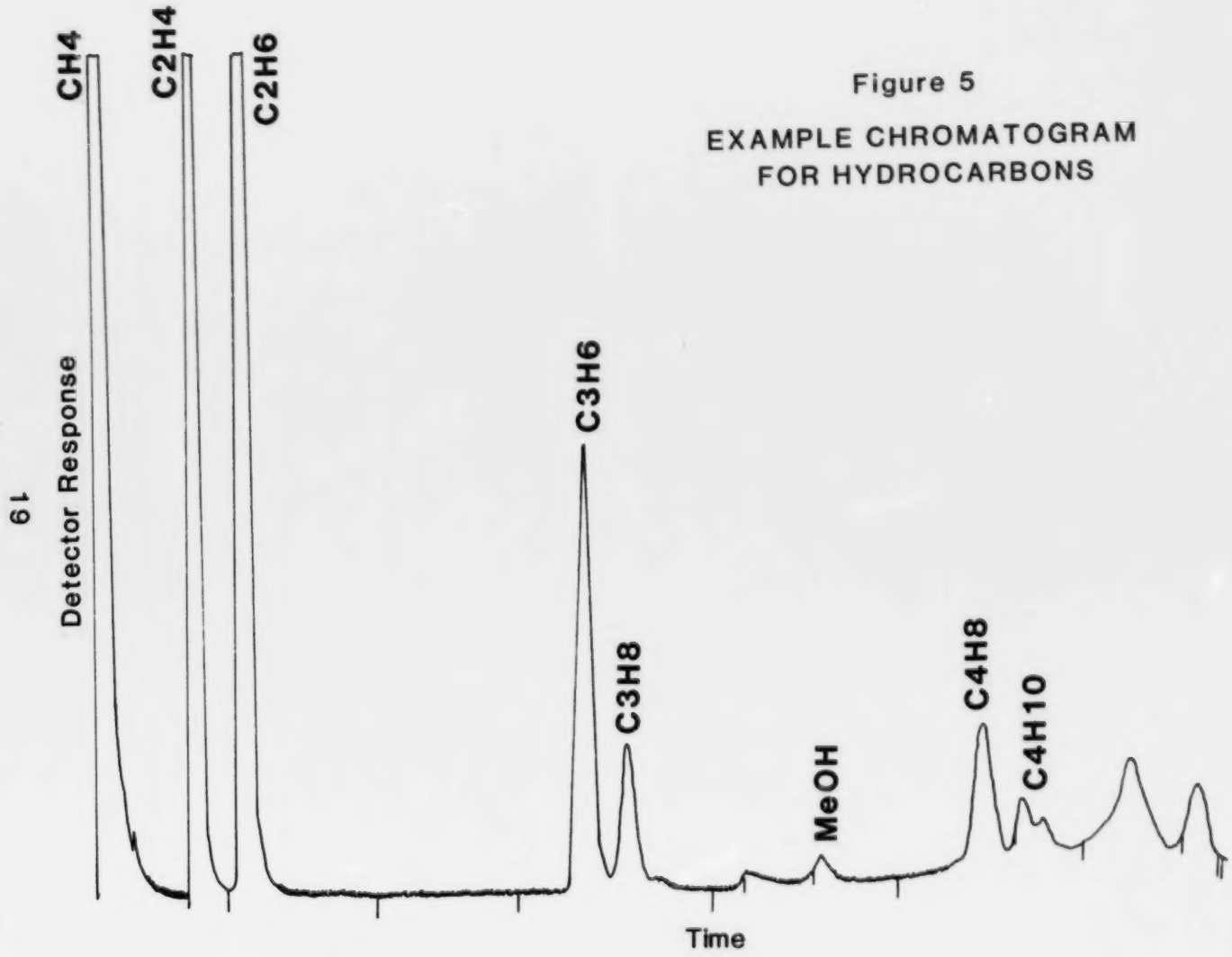
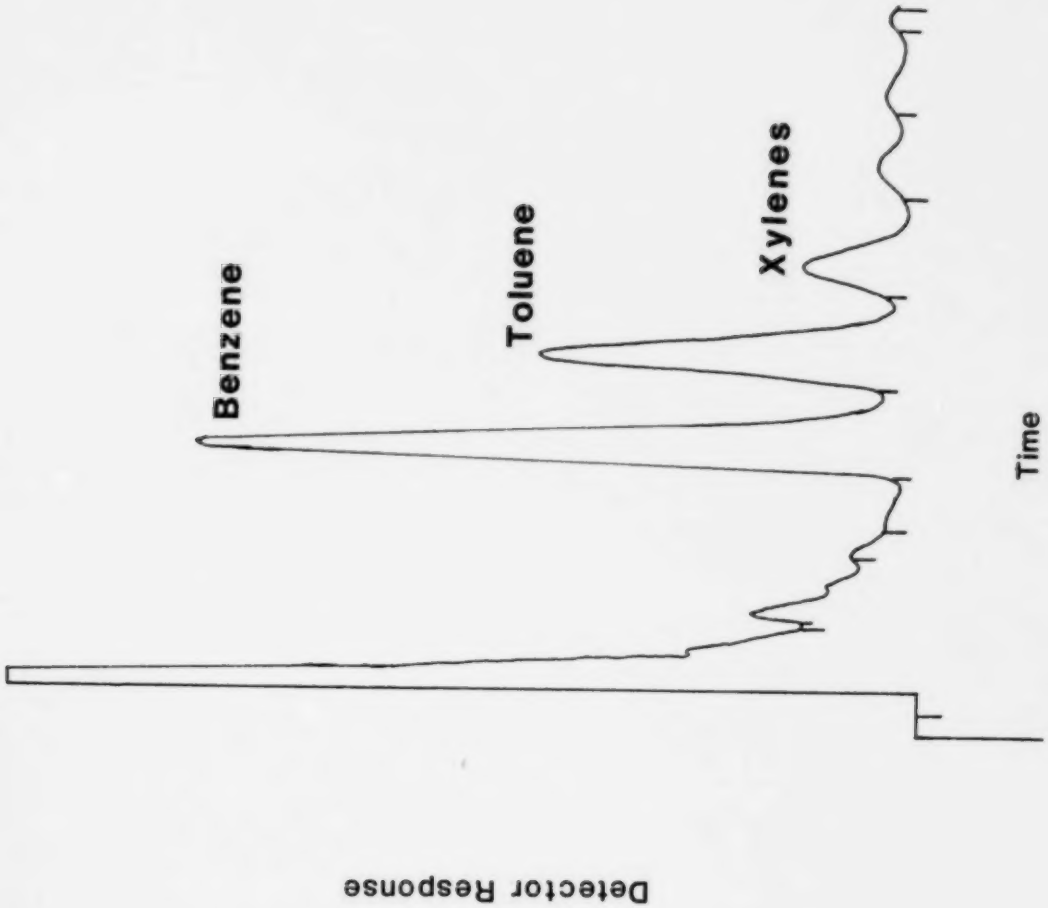


Figure 6

EXAMPLE CHROMATOGRAM
FOR AROMATIC HYDROCARBONS



GASS Computer Program

GASS is an interactive data reduction system designed to process, log, and retrieve gas chromatography data, and to generate reports of gas analysis results. GASS routines are written in Applied Information Systems (AIS) PL/I.

An example of the output of the GASS program is given in Table 2 for the analysis of the 12:30 PCS gas sample from GOP-6. Two replicate analyses are shown in the table. Also shown are the calibration curves used for the calculation of composition from peak areas. The percent recovery is calculated by totaling the micromoles calculated from the calibration curves and the peak areas, and dividing by the total micromoles injected from the gas sample loop. Since not all compounds present in the sample were included in the analysis, the percent recovery calculated for this sample is less than 100%.

TRACE METAL SAMPLING AND ANALYSIS

Feed peat, spent char, and cyclone fine samples were routinely collected and analyzed for arsenic, lead, and mercury. In addition, a small stream from the gas leaving the cyclone was diverted through the cold trap and/or a series of impingers and/or a series of gold amalgamation columns, all of which generated samples which were then analyzed for trace element content. A schematic diagram of the sample train used for trace metals is shown in Figure 7.

Solids were prepared for analysis by digesting one-gram samples in a Parr bomb under 30 atmospheres of O_2, with enough concentrated HNO_3 to have 0.5% HNO_3 in the final dilution. After cooling, the liquid in the bomb was rinsed into a 100 ml volumetric flask and diluted to volume with deionized water.

Following a run, the cold trap described earlier was opened and the packing was removed and its weight recorded. The packing was then soaked in about 1500 ml of HPLC-grade methylene chloride, which dissolved the tars and removed the particulates from the packing. The extract was then filtered and the residual solids were dried and weighed. The weight of tar was estimated from the net weight of the packing and the weight of recovered solids.

The methylene chloride solution containing the tar was evaporated down until all the solvent had been driven off, and the tar was then digested following the same procedure used for the solids. The tar trap water was digested by heating it with enough added HNO_3 to break down the organic constituents, which would otherwise cause interference in the spectrometric analysis.

TABLE 2
NCSU COAL GASIFICATION PROJECT
GAS CHROMATOGRAPHY

CARLE GAS BOMB ANALYSIS 9/23/81

RUN NUMBER: GOP-6
BOMB NUMBER: 36
SAMPLE TIME: 12:00
DETECTOR: TCD
T = 349 K
LOOP SIZE = 1.00 ML

RUN DATE: 9/23/81
SAMPLE LOCATION: PCS
ANALYST: STEINSBERGER
INSTRUMENT: CARLE
P = 5.00 PSIG
DILUTION FACTOR = 1.00

CALIBRATION CURVES USED:

H2 6/29/81 .07< [A] < 7.19 r = .998
MIC-MOLES = 0.0000E+00*[A]**3 + 0.0000E+00*[A]**2 +
4.1229E+00*[A]** 1.0000E+00 + 3.2627E-01

CO2 8/19/81 .01< [A] < 54.00 r = .998
MIC-MOLES = 0.0000E+00*[A]**3 + 0.0000E+00*[A]**2 +
3.7234E-01*[A]** 1.0000E+00 + 4.2495E-02

CH4 8/19/81 3.00< [A] < 25.00 r = .998
MIC-MOLES = 0.0000E+00*[A]**3 + 0.0000E+00*[A]**2 +
4.8578E-01*[A]** 1.0000E+00 + -1.8341E-02

C2H4 8/19/81 .20< [A] < 3.00 r = .999
MIC-MOLES = 0.0000E+00*[A]**3 + 0.0000E+00*[A]**2 +
3.1330E-01*[A]** 1.0000E+00 + 1.8138E-02

C2H6 8/18/81 .50< [A] < 3.00 r = .998
MIC-MOLES = 0.0000E+00*[A]**3 + 0.0000E+00*[A]**2 +
3.3830E-01*[A]** 1.0000E+00 + 2.0488E-02

N2 6/30/81 2.00< [A] < 70.00 r = .998
MIC-MOLES = 0.0000E+00*[A]**3 + 0.0000E+00*[A]**2 +
4.3745E-01*[A]** 1.0000E+00 + -5.4394E-01

CO 6/30/81 1.29< [A] < 60.00 r = .998
MIC-MOLES = 0.0000E+00*[A]**3 + 0.0000E+00*[A]**2 +
4.4092E-01*[A]** 1.0000E+00 + -1.3328E-01

H2S 8/19/81 .69< [A] < 2.00 r = .998
MIC-MOLES = 0.0000E+00*[A]**3 + 0.0000E+00*[A]**2 +
3.6826E-01*[A]** 1.0000E+00 + 5.2120E-03

TABLE 2 CONTINUED

GOP-6 9/23/81

BOMB NO. 36 GAS COMPOSITION

PCS 12:00

SUMMATION ANALYSIS METHOD

SAMPLE TYPE	AREA	MICROGRAM MOLES	MOLE PERCENTS
SAMPLE 1			
H2	2.4791	10.5475	23.8330
CO2	21.7739	8.1498	18.4150
C2H4	.1731	.0723	.1635
C2H6	.2896	.1184	.2677
H2S	.0000	.0000	.0000
O2	.0000	.0000	.0000
N2	44.7206	19.0190	42.9750
CH4	2.8863	1.3838	3.1268
CO	11.5628	4.9650	11.2188
MICRO-MOLES INJECTED	46.7997		
PERCENT RECOVERY	99.56%		
SAMPLE 2			
H2	2.4716	10.5164	23.6747
CO2	21.7984	8.1589	18.3674
C2H4	.1739	.0726	.1635
C2H6	.2921	.1193	.2686
H2S	.0000	.0000	.0000
O2	.0000	.0000	.0000
N2	44.9458	19.1176	43.0376
CH4	2.9413	1.4105	3.1753
CO	11.6992	5.0251	11.3126
MICRO-MOLES INJECTED	46.7997		
PERCENT RECOVERY	99.91%		

STATISTICAL MOLE PERCENT ANALYSIS BOMB 36

PCS 12:00 9/23/81

GAS	MEAN	DEVIATION	+LIMIT	-LIMIT
H2	23.7540	.1119	24.7596	22.7480
CO2	18.3914	.0336	18.6940	18.0884
C2H4	.1635	.0000	.1638	.1632
C2H6	.2681	.0006	.2739	.2623
H2S	.0000	.0000	.0000	.000
O2	.0000	.0000	.0000	.0000
N2	43.0060	.0443	43.4046	42.6080
CH4	3.1511	.0343	3.4596	2.8425
CO	11.2655	.0663	11.8619	10.6694

Mercury in the gas stream was captured using a gold packing, with which it formed an amalgam. The sampling system consisted of a filter for particulate removal, a silver catalytic oxidizer, three gold amalgamation columns in series, and a wet test meter for gas flow rate measurements. The oxidizer was maintained at a temperature of about 320°C to convert any alkyl mercury to elemental mercury, since the former does not amalgamate with the gold. The high temperature also prevents mercury from forming an amalgam with the silver.

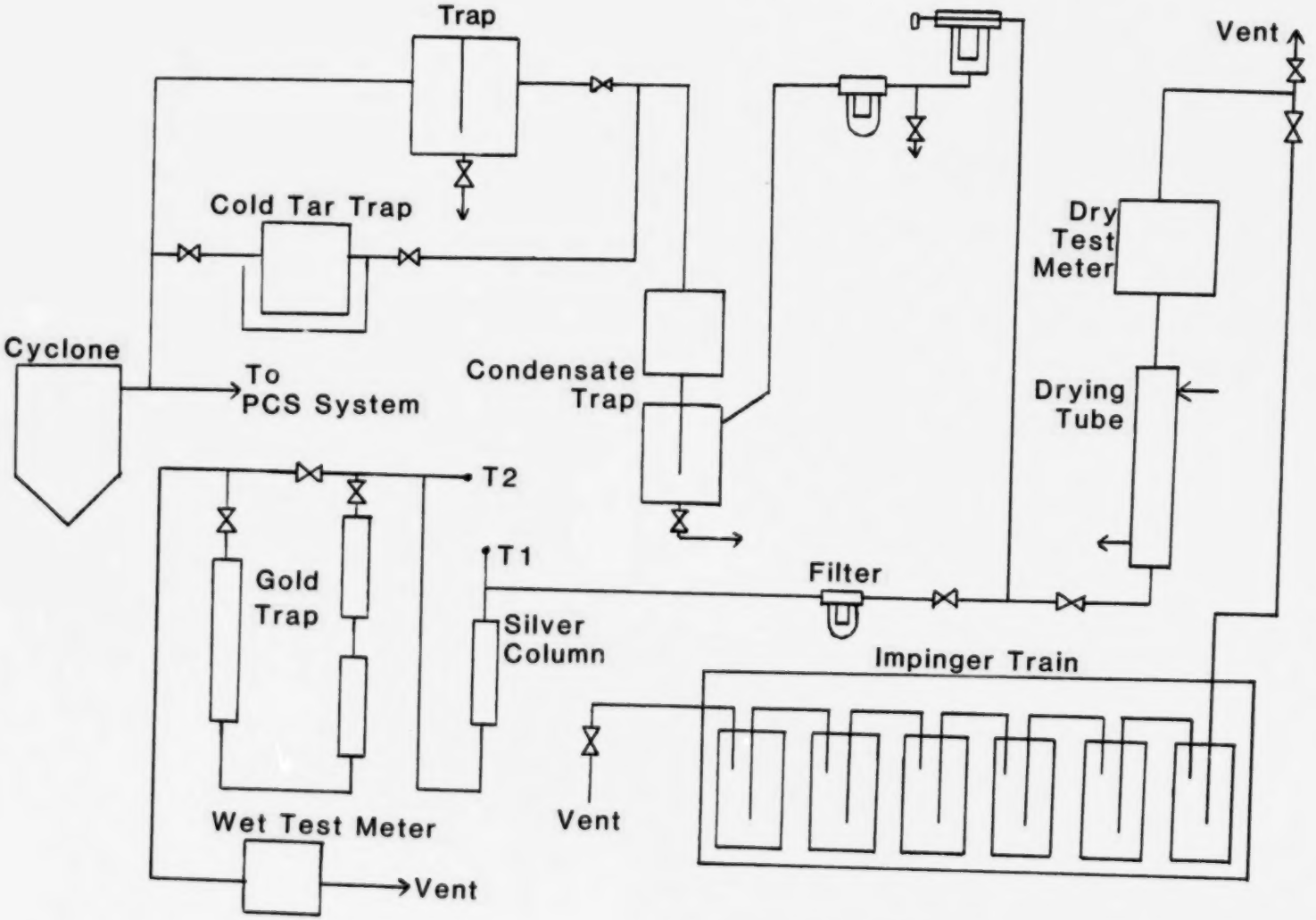
Following a run, the gold packings were removed and each of the traps was heated in a tubular furnace at about 600°C under a small nitrogen flow, into which the mercury desorbed. The gas stream was bubbled through a solution containing acidified $KMnO_4$. The solutions were then stored for subsequent Hg cold vapor analysis.

All trace element analyses were carried out using a Perkin-Elmer Model 603 Atomic Absorption Spectrophotometer. An HGA-2200 graphite furnace was used for the analyses of arsenic and lead, while mercury was determined by a cold vapor method. Ramp heating was used for the drying and charring steps, and normal, temperature controlled, or time controlled heating was used during atomization. Deuterium background correction was used for arsenic and lead analyses. Electrodeless Discharge Lamps were employed in all cases.

For arsenic determination, the wavelength and slitwidth were set at 197.2 and 0.7 nm respectively. Fifty ul samples were introduced into the furnace and were then dried at 125° C for 50 seconds, charred at 1000° C for 30 seconds, and atomized at 2700° C for 8 seconds. The ramp time for the drying and charring steps were 10 seconds each. A pyrolitically coated furnace tube was used for arsenic to provide greater durability at the higher atomization temperature. Nickel complexation was also used to allow high temperature charring.

For lead determination, the wavelength and slitwidth were set at 217.0 and 0.7 nm respectively. Twenty ul samples were dried at 125° C for 20 seconds, charred at 600° C for 45 seconds, and atomized at 2300° C for 8 seconds. The ramp time for the drying and charring steps were 10 seconds each. The method of standard additions was used for both arsenic and lead analyses.

Direct calibration methods were employed for the analysis of mercury. The wavelength and slitwidth settings for mercury were 254 nm and 0.7 nm respectively.



TRACE ELEMENT SAMPLE SYSTEM

Figure 7

DESCRIPTION OF RUNS

The peat used in this experimental program was obtained from First Colony Farms, Inc., from an operating site in Washington County, North Carolina. First Colony Farms harvests peat as milled peat and as an extruded and dried solid. The peat bog contains a substantial amount of wood throughout its depth, and this wood is broken up and harvested with the peat by both methods of harvesting.

The milled peat is harvested by allowing the surface of a prepared section of peat bog to dry. The surface is then milled to a depth of one to two inches and the milled material is gathered and stored in piles. The extrusion method of harvesting collects the wet peat to a depth of about 18 inches and extrudes it into cylinders about four inches in diameter. These are then allowed to dry in the field. When dried and ground, this material would probably make an acceptable gasifier feed.

The milled peat used in this study was a mixture of fibrous material, small pieces of wood, particles of solid peat, and a fairly large amount of fine material. The milled peat was loaded into 55 gallon drums from a pile in the field, transported to Raleigh, and stored for use. The moisture content of the peat as drummed was approximately 50%. The peat was prepared for gasification by screening through 1/4 inch hardware cloth and air dried at room temperature to a moisture content of about 25%. The peat was fed to the gasifier without any further preparation.

Startup of the fluidized bed gasifier was accomplished by loading 25 pounds of pretreated Western Kentucky No. 11 coal char into the reactor and heating with a fluidizing stream of hot nitrogen to a bed temperature of about 500°F. The purpose of this step was to heat the reactor vessel, the exit lines, and the cyclone to as high a temperature as possible without condensing any moisture or tar in the lines. Following this heating step, peat feed was started at a relatively low rate and a flow of oxygen was started when the bed temperature reached about 600°F. Steam flow was started at a bed temperature of about 1300°F, and the reactor was then brought to a steady state condition as rapidly as possible.

For most of the runs, the fluidized bed gasifier worked well; however, with the top feed arrangement, most of the gas production took place in the zone above the fluidized bed by devolatilization. Only a small fluidized bed height of about 15 to 20 inches could be maintained, even when the peat feed was at the highest rate possible. The gasifier apparently acted as a two

stage gasifier with a small fluidized bed of peat char in the lower zone and a devolatilization zone in the region above the bed.

Since the milled peat consisted of a mixture of fibrous and particulate material, with a substantial amount of fines in it, it had a tendency to pack into a solid mass and was not easy to feed with a screw conveyor feed mechanism under the best of conditions. Any reactor upset which could cause reactor make gas, with a high water and volatile hydrocarbon content, to flow back into the cold feed zone, would cause water and tar to condense in the feed screw region, and would cause the feed screw to jam and stop. When this happened, the run usually had to be stopped.

For the runs to be described, the numbering system in use is essentially the same as that used for the char and coal runs, and is outlined below:

For the Gasifier	For the Acid Gas Removal System
G - Gasifier	A - Acid Gas Removal System
O - Oxygen	M - Methanol Solvent
P - Peat	I - Integrated Run (Feed is Gasifier Make Gas)
1 - Number of Run	P - Peat
	1 - Number of Run

A summary of gas analysis data and mass balance results for all gasifier and acid gas removal system runs are given in Appendices B, C, and D. A brief description of all runs is given below:

GOP-1 June 17, 1981

This first run was a gasifier run only, and was made to determine the best conditions for operation of the gasifier with peat. As an example of the notes made during a run, a copy of the note file, kept on the data acquisition system during the run, is given in Appendix A.

Figures 8-13 are plots made from the five-minute average data saved by the data acquisition system, and show several of the most important process variables from the gasifier-PCS system plotted versus time. A number of changes were made during the day in an attempt to determine the best operating conditions for the gasifier. These changes can be followed by reference to the note file (Appendix A) and the process variable plots.

The mean residence time for the gases in the gasifier-PCS system is approximately 20 minutes, and therefore conditions must be maintained constant for at least one hour to achieve good steady state concentrations at all points in the system. Two such steady state periods were attempted during this run, and two sets of gasifier gas samples were taken for analysis. The first complete set of gas samples was taken at about 13:15, and is indicated as event marker 2 on the plots. For the mass balances, the

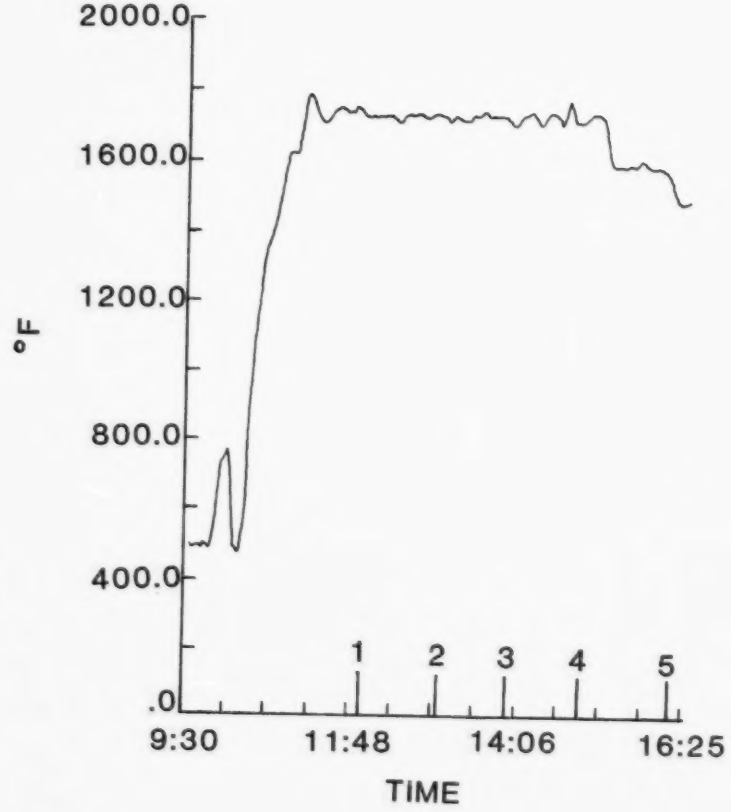


Figure 8

GASIFIER BED TEMPERATURE
AT 5 INCHES ABOVE GAS FEED

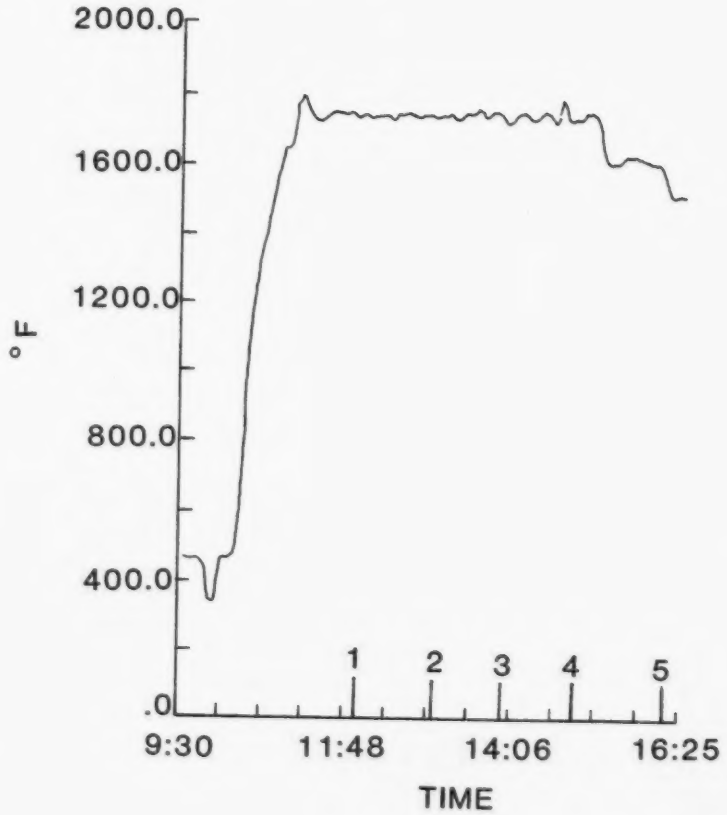


Figure 9

GASIFIER BED TEMPERATURE
AT 10 INCHES ABOVE GAS FEED

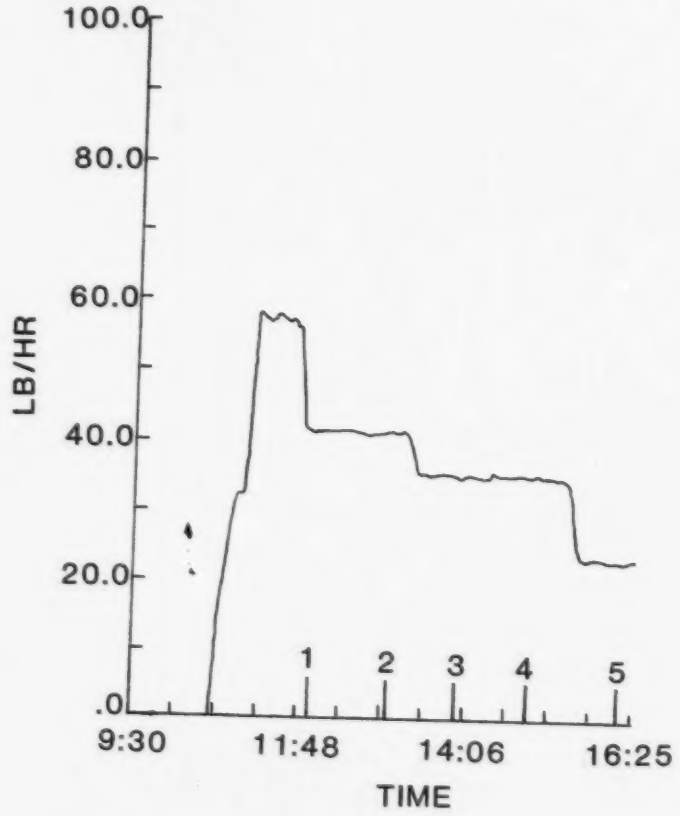


Figure 10

STEAM FEED RATE TO GASIFIER

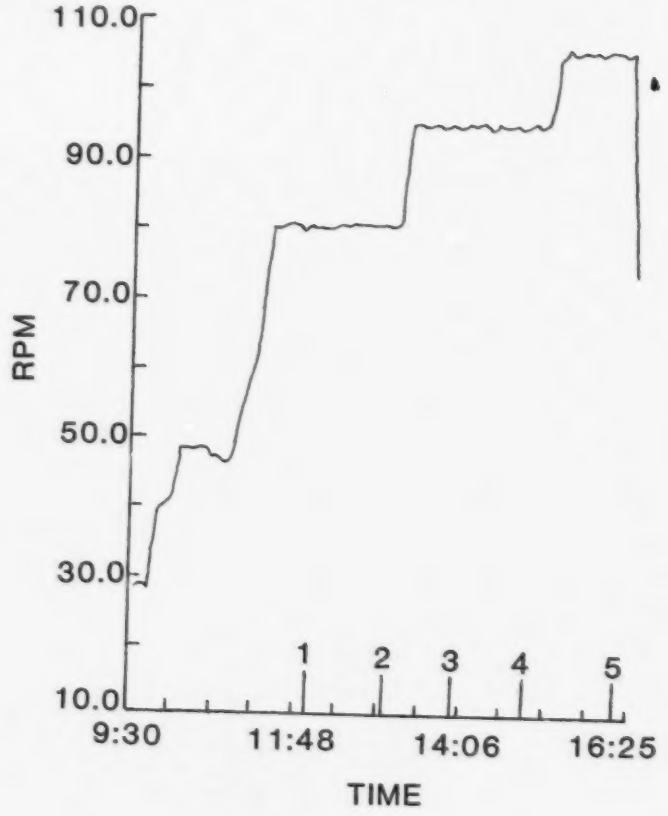


Figure 11

PEAT FEED SCREW RATE

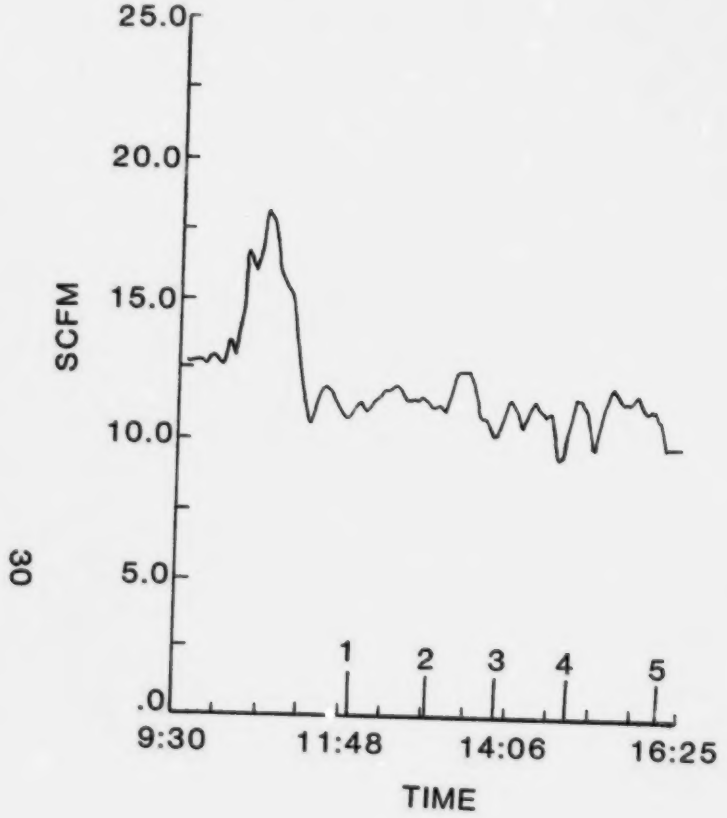


Figure 12

GASIFIER MAKE GAS FLOW RATE (DRY)

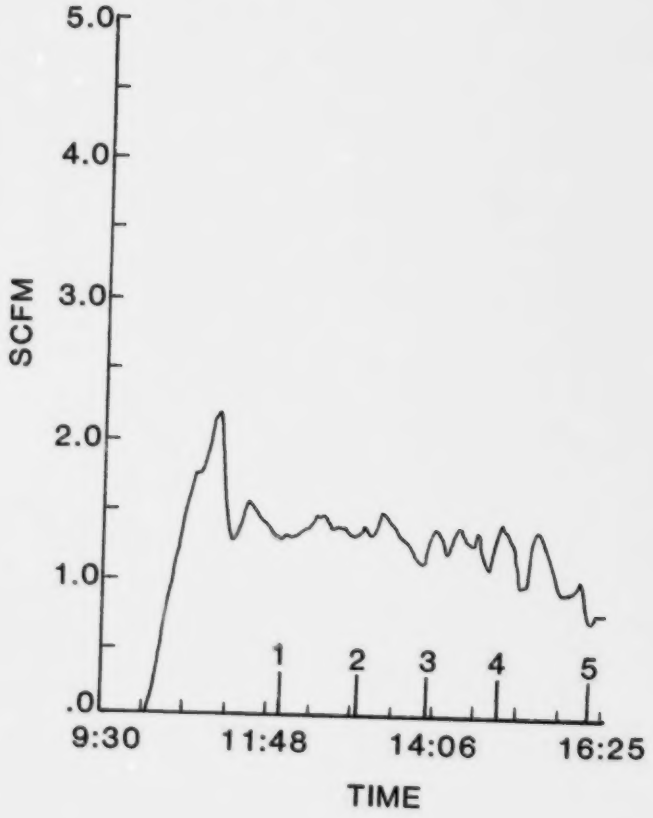


Figure 13

OXYGEN FEED RATE TO GASIFIER

process variables stored by the data acquisition system are averaged over a steady state period just prior to the sample time. The period between event markers 1 and 2 indicates the steady state period for the mass balance shown in Appendix C. Event markers 3 and 4 indicate a second steady state period (samples were taken at 4), and 5 marks the time at which the facility was shut down. The mass balance for the first steady state period shown is excellent, however, that for the second period was not satisfactory, probably because of faulty samples, and is not included.

In addition to the sets of gas samples taken for later analysis, a number of samples were taken for immediate analysis on the Carle GC. The results of all gas analyses for the major gases H_2, CO_2, CO, and CH_4, are shown as a function of time in Figure 14. None of the changes in operating conditions made during this run had a major effect on the make gas composition.

Several combinations of good operating conditions can be located for this run. However, since the AGRS requires a make gas flow rate of at least 15 SCFM, the flow rate achieved in this run was too low to provide an adequate feed to the AGRS. Run GOP-2, to be discussed next, was an attempt to define a better optimum operating condition for the gasifier.

GOP-2 June 25, 1981

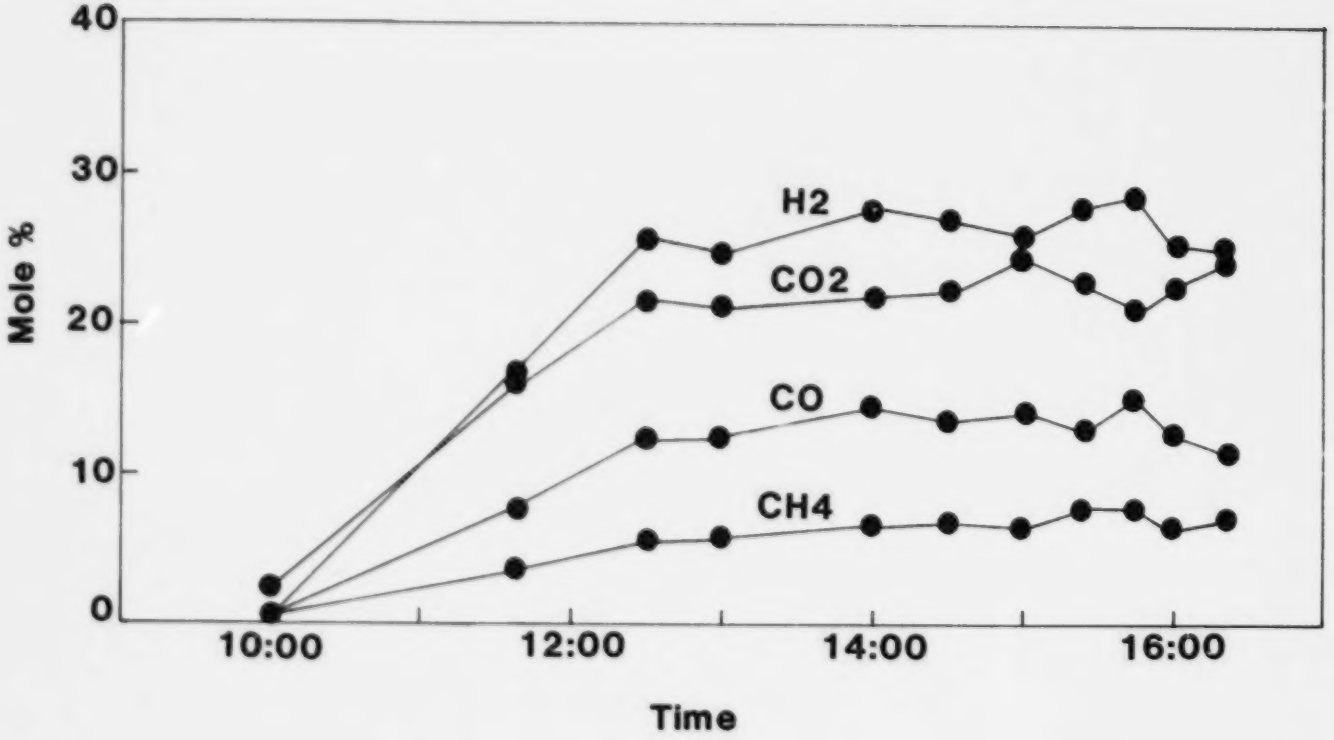
Since a large fraction of the reactor make gas is produced during devolatilization and pyrolysis, a higher peat feed rate was indicated in order to increase the make gas flow rate. In an attempt to determine an optimum, conditions for this run were changed several times during the day and the changes were followed by gas analysis and process variable plots in the same way as described for GOP-1. Once again, changes in reactor operating conditions had very little effect on make gas composition. Since reactor conditions were changing almost continuously, no satisfactory mass balances were achieved.

As a result of the first two runs, the following conditions were determined to be satisfactory for gasifier operation, and to yield a reactor make gas rate sufficient for AGRS operation:

Peat feed rate:	60 - 70 Lb/Hr (150 RPM)
Steam feed rate:	30 - 35 Lb/Hr
Bed Temperature:	1600 - 1700°F
Gasifier Make Gas Rate:	16 - 19 SCFM

Figure 14

COMPOSITION VERSUS TIME
FOR GOP-1



GOP-3 - AMIP-1 July 7, 1981

This run was intended to be the first integrated run with peat, but was terminated before any useful information was obtained when the packing on the char removal screw blew out.

GOP-3 - AMIP-1 July 15, 1981

This run was terminated before a satisfactory steady state was reached for the AGRS due to a failure of the hydraulic system used to power the feed and removal screws. A full set of gasifier gas samples was taken before the failure, and the mass balance results for this run are given in Appendix C.

GOP-4 - AMIP-2 August 12, 1981

This run was terminated before any useful results were obtained due to failure of the packing on the char removal screw.

GOP-4B - AMIP-2 August 19, 1981

Good steady state samples for the gasifier were taken at 11:10 and the results of these sample analyses are shown in Appendix B. At about 11:55, the feed screw jammed and could not be started. A complete set of AGRS samples was taken. The sample train cold trap was in operation for a full hour, and resulted in good samples of condensed liquids from the gasifier make gas. This was a successful integrated run, although somewhat shorter than intended. Mass balances are given in Appendix C and D.

GOP-5 - AMIP-3 September 9, 1981

This run failed before any useful information could be obtained because of a jammed feed screw.

GOP-5B - AMIP-3 September 15, 1981

This run failed before any useful information could be obtained due to failure of the hydraulic system.

GOP-6 - AMIP-3 September 23, 1981

This was a successful, integrated run, and gas analyses and mass balances are given in the Appendices.

RESULTS AND DISCUSSION

GASIFIER OPERATION

Five gasifier runs were completed successfully using a feed of North Carolina peat. The first two runs, GOP-1 and GOP-2, were mainly for the purpose of determining satisfactory operating conditions. For these two runs the conditions were changed frequently, and good mass balances were difficult to obtain. The mass balance for GOP-2 was poor; however, the results from GOP-2 generally agree with the other experimental results and are included in the following sections. GOP-3, GOP-4B, and GOP-6 used operating conditions determined from the results of the initial two peat runs. The principal results from all peat runs are summarized in Table 3, and complete results for the gasifier are given in Appendix C.

It is interesting to compare the results of the gasification of North Carolina peat with the gasification of the New Mexico subbituminous coal carried out with the pilot plant facility prior to the runs with peat. In general, lower operating temperatures were used in peat gasification than in the gasification of the New Mexico coal, and the product gas yields obtained from both were of similar magnitude. The higher feed rates used in the peat runs were probably a major factor in this result, but the similar product rates at lower temperatures may also reflect a greater reactivity of the peat relative to the coal. Comparisons of peat and coal runs are difficult due to the different operating conditions used in most cases; however, one coal run, GO-78, does compare reasonably well with peat run GOP-4B. A summary of gasifier conditions for the peat run, GOP-4B, and the New Mexico subbituminous coal run, GO-78, is given in Table 4. When allowances are made for the much higher moisture content of the peat feed, the conditions of the two runs were almost identical. These two runs form an excellent basis for comparison, and will be used in several sections of this report.

TABLE 3
SUMMARY OF RUNS FOR GASIFIER-AGRS
USING NORTH CAROLINA PEAT AND METHYL ALCOHOL

Gasifier	GOP-1	GOP-2	GOP-3	GOP-4B	GOP-6
Date	6/17/81	6/25/81	7/15/81	8/19/81	9/23/81
Avg Bed Temp, °F	1730	1602	1582	1607	1632
Pressure, psig	102	104	104	105	105
Peat feed, lb/hr	37.0	68.6	57.6	57.9	71.6
Steam feed, lb/hr	41.6	25.3	32.4	33.1	35.3
Oxygen feed, SCFM	1.37	2.31	2.16	1.86	2.46
Steam/Carbon ratio	1.70	0.57	0.84	0.83	0.72
Oxygen/Carbon ratio	0.17	0.16	0.17	0.14	0.15
Carbon conversion %	64.8	62.1	64.6	57.7	57.2
Dry make gas, SCFM	13.4	18.3	18.6	17.1	18.5
Sweet gas heating value, Btu/SCF	323	387	352	327	393
Mass balance closure %	98.8	90.8	97.3	101.0	100.1

AGRS	----	----	----	AMIP-2	AMIP-3
Date				8/19/81	9/23/81
Absorber pressure, psig				347	447
Absorber temperature, °F				-21	-37
Absorber packing height, ft				14.2	14.2
Liquid solvent flow, gpm				0.87	1.20
Gas flow to absorber, SCFM				13.2	13.6
Flash tank pressure, psig				147	147
Stripper pressure, psig				9.9	9.9
Stripper tempperature, °F				48	48
Stripper packing height, ft				21.3	21.3
Stripper nitrogen flow, SCFM				1.19	1.19
Mass balance closure %				100.9	99.4

TABLE 4
SUMMARY OF GASIFIER CONDITIONS FOR GOP-4B AND GO-78

	GOP-4B	GO-78
Pressure, psig	104.7	103.9
Temperature, °F	1607	1606
Coal/Peat Feed, lb/hr	57.9	41.1
Moisture Content of Feed, %	22.3	9.6
Coal/Peat Feed, Dry Basis, lb/hr	45	37
Steam Feed, lb/hr	33	57
Steam/Carbon Ratio	0.83	1.71
Dry Make Gas Flow, SCFM	17.1	15.9

EMISSIONS FROM THE GASIFIER-PCS SYSTEM

The material in this section is organized to present detailed chemical analyses and emissions of the various solid, gaseous, and liquid streams, in the order of their occurance in the pilot plant.

Solid Streams

Proximate and ultimate analyses of the feed peat, the solid samples collected from the cyclone, and the spent char are given in Tables 5 and 6. As mentioned in an earlier section of this report, the cyclone did not perform consistantly for these runs, and the cyclone samples are therefore somewhat questionable. With this exception, the data shown in the tables are as expected. Since conditions in the gasifier did not vary significantly for the runs made, the solids analysis results are all very similar. The high carbon content of the spent char is a result of the very low ash content of the peat, and is not an indication of the overall carbon conversion of the gasification process. The carbon conversion for these runs was discussed in the preceeding section of this report.

A detailed trace metal analysis for arsenic, lead, and mercury was made for run GOP-4B, and these results will be presented later in this section.

TABLE 5
PROXIMATE ANALYSIS OF PEAT SOLIDS Wt %

	GOP-1	GOP-2	GOP-3	GOP-4B	GOP-6
Feed					
Moisture	27.50	27.36	24.49	22.85	23.35
Standard Dev.	0.629	0.361	0.064	0.156	0.085
Volatile Matter	44.30	44.05	44.67	46.32	44.88
Standard Dev.	0.939	0.382	0.049	0.184	0.244
Ash	3.26	3.73	4.42	4.62	5.00
Standard Dev.	0.187	0.160	0.027	0.218	0.141
Fixed Carbon	24.94	24.87	26.43	26.20	26.77
Standard Dev.	1.145	0.549	0.085	0.325	0.294
Char					
Moisture	1.56	3.08	*14.22	4.32	0.64
Standard Dev.	0.035	0.035	*0.113	0.113	0.071
Volatile Matter	9.48	7.75	*42.22	8.94	4.93
Standard Dev.	0.898	0.165	*0.103	0.291	0.569
Ash	25.74	33.46	*7.03	38.72	28.97
Standard Dev.	1.893	1.227	*0.020	0.854	1.721
Fixed Carbon	63.23	55.71	*36.38	48.02	65.46
Standard Dev.	2.096	1.238	*0.144	0.909	1.814
Cyclone					
Moisture	2.59	2.61	7.26	1.61	1.82
Standard Dev.	0.085	0.007	0.099	0.028	0.028
Volatile Matter	18.22	13.11	10.88	11.02	12.73
Standard Dev.	0.091	0.393	0.335	1.405	0.729
Ash	14.80	13.41	17.40	18.13	15.01
Standard Dev.	0.269	0.117	0.068	0.022	0.111
Fixed Carbon	64.39	70.87	64.46	69.24	70.44
Standard Dev.	0.296	0.410	0.356	1.406	0.738

*Bad Sample - Analysis was repeated twice

TABLE 6
ULTIMATE ANALYSIS OF PEAT SOLIDS Wt %

	GOP-1	GOP-2	GOP-3	GOP-4B	GOP-6
Feed					
Carbon	43.97	42.76	44.53	45.89	45.41
Standard Dev.	0.304	0.050	0.354	1.018	0.290
Hydrogen	4.09	3.90	4.15	4.33	4.16
Standard Dev.	0.042	0.057	0.050	0.071	0.099
Nitrogen	0.85	0.91	0.93	0.91	1.05
Standard Dev.	0.113	0.106	0.014	0.028	0.014
Sulfur	0.1409	0.1733	0.1369	0.1460	0.1715
Standard Dev.	0.0001	0.005	0.003	0.002	0.016
Oxygen	47.69	48.53	45.83	44.10	44.21
Standard Dev.	0.327	0.130	0.357	1.021	0.307
Char					
Carbon	56.42	64.00	*54.73	39.43	51.04
Standard Dev.	0.622	0.905	*0.021	4.957	12.473
Hydrogen	1.47	1.15	*3.93	1.10	0.65
Standard Dev.	0.050	0.007	*0.050	0.134	0.262
Nitrogen	0.88	0.70	*1.35	0.71	0.46
Standard Dev.	0.085	0.021	*0.028	0.000	0.000
Sulfur	0.0944	0.0844	*0.3742	0.2464	0.3524
Standard Dev.	0.006	0.008	*0.010	0.012	0.027
Oxygen	15.40	0.60	*32.59	19.79	18.53
Standard Dev.	0.630	0.905	*0.062	4.959	12.476
Cyclone					
Carbon	70.71	73.51	67.30	69.38	72.72
Standard Dev.	0.891	0.354	0.092	5.501	3.04
Hydrogen	2.48	2.13	1.59	1.63	1.79
Standard Dev.	0.007	0.071	0.042	0.156	0.184
Nitrogen	1.28	1.13	1.27	1.05	0.60
Standard Dev.	0.021	0.099	0.014	0.000	0.000
Sulfur	0.1059	0.0835	0.0869	0.0885	0.0966
Standard Dev.	0.006	0.009	0.001	0.004	0.001
Oxygen	10.62	9.74	12.35	9.72	9.78
Standard Dev.	0.891	0.374	0.102	5.503	3.046

Gases

Gas analyses for all of the runs made with peat are given in Appendix B. The times at which the samples were taken are noted in the tables and correspond to the times of the mass balances given in Appendices C and D.

A comparison of sample train gas analysis for peat run GOP-4B and coal run GO-78 is given in Table 7. The two compositions show little major differences except for the sulfur species. This is undoubtedly due to the difference in the sulfur content of the feed materials, since the ratio of total sulfur in the two product gases is the same as the ratio of sulfur in the feed materials. The peat run has slightly more CO and CO_2 in its product gas, while the product gas from the coal run has slightly more methane. The higher concentrations of methane from the New Mexico coal, compared to peat, is consistent with the results of a series of independent devolatilization studies on these materials.

Production rates, calculated as grams produced per kilogram of peat or coal fed, are tabulated in Table 8 for various sulfur and hydrocarbon gases. For the gasification of New Mexico coal, production rates varied widely, thus a range of values is reported. The procuction from peat gasification showed little variance, and average values are listed. Also included in Table 8 are the production rates from runs GO-78 and GOP-4B. The data indicate that in general, hydrocarbons produced are of similar magnitude in both coal and peat gasification, while the sulfur gas production is much greater in the gasification of the New Mexico coal. As previously stated, the difference in the sulfur gases produced is a result of the differences in the sulfur content of the two feed materials. A comparison of the individual runs shows the same general trend for the gases, ethane, and ethylene. However, the peat run has a greater benzene production rate than the coal run, while the methane production rate is greater for the coal run.

TABLE 7
COMPARISON OF SAMPLE TRAIN GAS ANALYSIS FOR GOP-4B AND GO-78

Species	GOP-4B Peat Run Mole %	GO-78 Coal Run Mole %
H_2	28.40	27.49
CO	15.56	11.94
CH_4	5.65	8.46
CO_2	23.17	21.88
N_2	25.94	30.21
H_2S	0.04	0.24
COS	0.002	0.007
Thiophene	0.001	0.003
CH_3SH	0.002	0.005
Ethylene	0.44	0.33
Ethane	0.65	0.46
Propylene	0.53	0.12
Propane	0.14	0.05
Butane	0.07	0.02
Benzene	0.11	0.02
Toluene	0.04	0.04

TABLE 8
COMPARISON OF GASEOUS PRODUCTION FROM GASIFICATION
OF NEW MEXICO COAL AND NORTH CAROLINA PEAT
Grams produced per kg of feed

	N.M. Coal		N.C. Peat	
Species	Range for all runs	GO-78	Avg for all runs	GOP-4B
H_2S	2.8 - 9.9	5.4	0.9	0.7
COS	0.14 - 0.56	0.29	0.07	0.06
CH_3SH	0.02 - 0.17	0.17	0.08	0.05
Thiophene	0.07 - 0.27	0.16	0.07	0.05
CH_4	43 - 106	88	52	45
Ethane	6.8 - 23.1	7.8	10.0	9.3
Ethylene	5.1 - 13.2	6.0	7.6	5.8
Benzene	0.9 - 9.1	0.9	3.5	4.1

Liquids

Waste Water---

Both the PCS tank water and the sample train condensate water were analyzed as described in the analytical methods section of this report. The results are given in Tables 9 and 10 for all of the runs made. Samples from the PCS tank were collected after the completion of a run, and thus represent the accumulation of material during the times of startup, steady state operation, and shutdown. In addition, the concentration of the various compounds in the PCS tank water depends upon the length of the run. The sample train condensate water is collected during the steady state portion of a run, and thus is a valid representation of waste water from a run. The analyses of the PCS tank water are useful for general information, however, the sample train condensate analyses should be used for quantitative data.

TABLE 9
SUMMARY OF PCS TANK WATER ANALYSIS (mg/l except pH)

	GOP-1	GOP-2	GOP-4B	GOP-6
Ammonia	333	184	409	354
Carbon	960	670	1110	1240
Chloride	28	27	N/A	26
COD	2530	1620	4640	2970
Cyanate	27	30	28	101
Cyanide	N/A	10	1	20
Fluoride	2	1.3	N/A	5
Nitrogen	378	210	454	427
pH	7.7	7.8	7.7	7.5
Phenolics	83	42	118	124
Sulfate	34	29	N/A	25
Sulfite	20	<3	N/A	<3
Thiocyanate	38	12.3	N/A	15
TOC	900	490	950	950
TVC	270	330	460	522

N/A - Not Analyzed

TABLE 10
SUMMARY OF SAMPLE TRAIN COLD TRAP WATER ANALYSIS
Concentrations in mg/l except pH

	GOP-1	GOP-2	GOP-3	GOP-4B	GOP-6
Ammonia	3941	7797	7970	7919	5270
Carbon	10400	13100	18000	11400	15700
Chloride	120	116	180	50	110
COD	30500	39400	38600	34200	39600
Cyanate	1301	598	1770	870	1331
Cyanide	37	43	54	64	75
Fluoride	20	17	12	20	120
Nitrogen	4736	8700	9070	9804	6471
pH	8.3	8.5	8.7	8.2	8.9
Phenolics	808	1510	1720	1493	1320
Sulfate	20	12.3	10.6	20	<10
Sulfite	60	12	20	60	<10
Thiocyanate	386	238	430	N/A	270
TOC	9320	10500	11900	10600	13600
TVC	2520	6630	11000	4450	4240

Table 11 presents a comparison of the sample train cold trap water analysis for peat with New Mexico subbituminous coal. As was shown in Table 4, these two runs, GOP-4B and GO-78, were made at almost identical gasifier conditions, and thus the comparison should be valid. With the exception of dissolved carbon (Carbon, COD, TOC, and TVC) the results are nearly the same. The higher values for dissolved carbon are believed to be mostly in the form of phenols. This is consistent with several additional analyses to be discussed later, which indicate that the gasification of peat produces relatively higher amounts of phenols and other acidic compounds than the gasification of coal.

In addition to the analyses presented above, both the sample train condensate water and the PCS tank water were sampled and analyzed by GC/MS as described in the preceeding section of this report. The results presented here do not represent a complete analysis of the results from the GC/MS runs, and are essentially preliminary screening results. The data obtained from the GC/MS runs are stored on tape and will be subjected to more detailed compound identification analysis in the future.

TABLE 11
SAMPLE TRAIN COLD TRAP WATER ANALYSES FOR COAL AND PEAT
Concentrations in mg/l except pH

	Average Value or Range for all Runs		Concentrations	
	Peat	Coal	Peat GOP-4B	Coal GO-78
Ammonia	6,580	6,000	7,919	6,065
Carbon	13,720	3,200	11,400	3,380
Chloride	115	40	50	38
COD	36,460	6,000-10,000	34,200	9,350
Cyanate	600-1,770	2,000-5,000	870	1,749
Cyanide	55	25-200	64	167
Fluoride	20-120	10	20	10
Nitrogen	4,700-9,800	6,000	9,840	---
pH	8.5	8.5	8.2	8.5
Phenolics	1,370	600-1,100	1,493	772
Sulfate	14	40-300	20	28
Sulfite	37	40	60	55
Thiocyanate	330	250	---	233
TOC	11,200	2,600	10,600	2,760
TVC	3,800	1,500	4,450	1,630

Figure 15 shows the GC/MS scan of the base/neutral extract of the sample train water from run GOP-4B. This extract should contain the majority of the polynuclear aromatic compounds from the condensate water, and is thus of primary concern from an environmental point of view. The extract also contains a large amount of phenols and substituted phenols, which tends to confirm the relatively high phenol production from peat gasification.

Figures 16 and 17 show the results of the GC/MS scan of the base/neutral extract and the acid extract of the PCS tank water from GOP-6, prepared as described in the analytical methods section of this report. As can be seen, the base/neutral extract contains most of the polynuclear aromatic compounds, and the acid extract most of the phenolic compounds. Compared to previous results from coal gasification, the waste water from peat gasification contains less PNA compounds, and very few PNA's of high molecular weight.

FIGURE 15
GOP-4B SAMPLE TRAIN WATER (Base/Neutral Extract)

Peak No	Compound	Peak No	Compound
1	benzonitrile or isocyanobenzene	25	1H-indole
2	1-methoxy-4-methylbenzene	26	pentamethylbenzene or other $C_{11}H_{16}$ substituted benzene
3	methyl substituted benzonitrile	27	methyl substituted indole or indolizine
4	methyl substituted benzaldehyde	28	methoxy-propenyl substituted phenol
5	methyl substituted benzonitrile	29	methyl substituted indole or indolizine
6	3,4,5-trimethyl-2-cyclopenten-1-one	30	methyl substituted indole or indolizine
7	methyl substituted indole or indolizine	31	2-methoxy-4-(1-propenyl) phenol
8	dimethyl substituted phenol	32	dimethyl substituted indole or indolizine
9	methyl substituted indole or indolizine	33	3-hydroxyquinoline or substituted indole
10	naphthalene or methyl substituted indolizine	34	dimethyl substituted indole or indolizine
11	2-phenoxyethanol or other $C_8H_{10}O_2$	35	dimethyl substituted indanone
12	2-ethyl-5-methylphenol	36	cyclododecane
13	dimethyl substituted phenol	37	o-phenylphenol
14	trimethyl substituted phenol	38	fluorene
15	hydrocarbon	39	4-methoxydiphenyl
16	trimethyl substituted phenol	40	1-ethyl-2,3,4,5,6 pentomethylbenzene
17	1-methyl-1H-indole	41	p-benzylphenol
18	1-(2,4-dihydroxyphenyl)ethanone	42	cyclododecane
19	methyl ethyl substituted phenol	43	2,6-di-tert-butyl-4-ethylphenol
20	hydrocarbon	44	2,4,6-tri-tert-butylphenol
21	$C_9H_{10}O_2$ hydrocarbon	45	hydrocarbon
22	diethylphenol	46	carbazole
23	methyl ester of benzene acetic acid	47	C_{22} - C_{24} hydrocarbon
24	methyl-(1-methylethyl)substituted phenol	48	C_{25} hydrocarbon

FIGURE 15

Continued

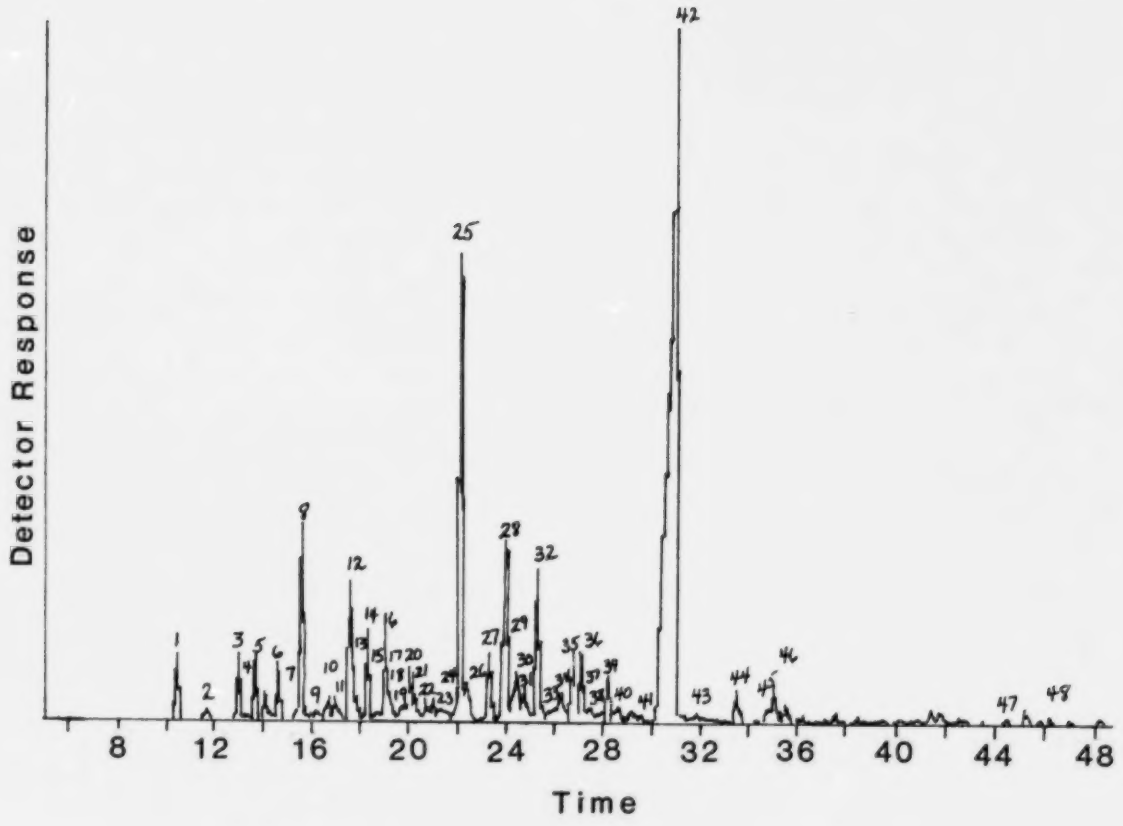


FIGURE 16
GOP-6 PCS Water (Base/Neutral Extract)

Peak No	Compound	Peak No	Compound
1	pyridine	17	phenol
2	toluene	18	?
3	cyclopentanone	19	napthalene
4	methylpyridine	20	?
5	3-ethylcyclopentene	21	quinoline or isoquinoline
6	2 (1H)-pyridinone	22	ethyl substituted phenol
7	hydrocarbon	23	dihydro substituted inden-1-one
8	1-(1H-pyrazol-4-yl)-ethanone	24	methylnapthalene
9	3,5-dimethylpyridine	25	methylnapthalene
10	3-methyl-2-cyclopenten-1-one	26	benzeneacteonitrile
11	5-methyl-2-furancarboxaldehyde	27	biphenylene or acenaphthylene
12	hydrocarbon	28	1,2-dihydroacenapthylene
13	benzofuran	29	dibenzofuran
14	hydrocarbon	30	9H-fluorene
15	1-propynylbenzene	31	phenanthene or anthracene
16	1-phenylethonone		

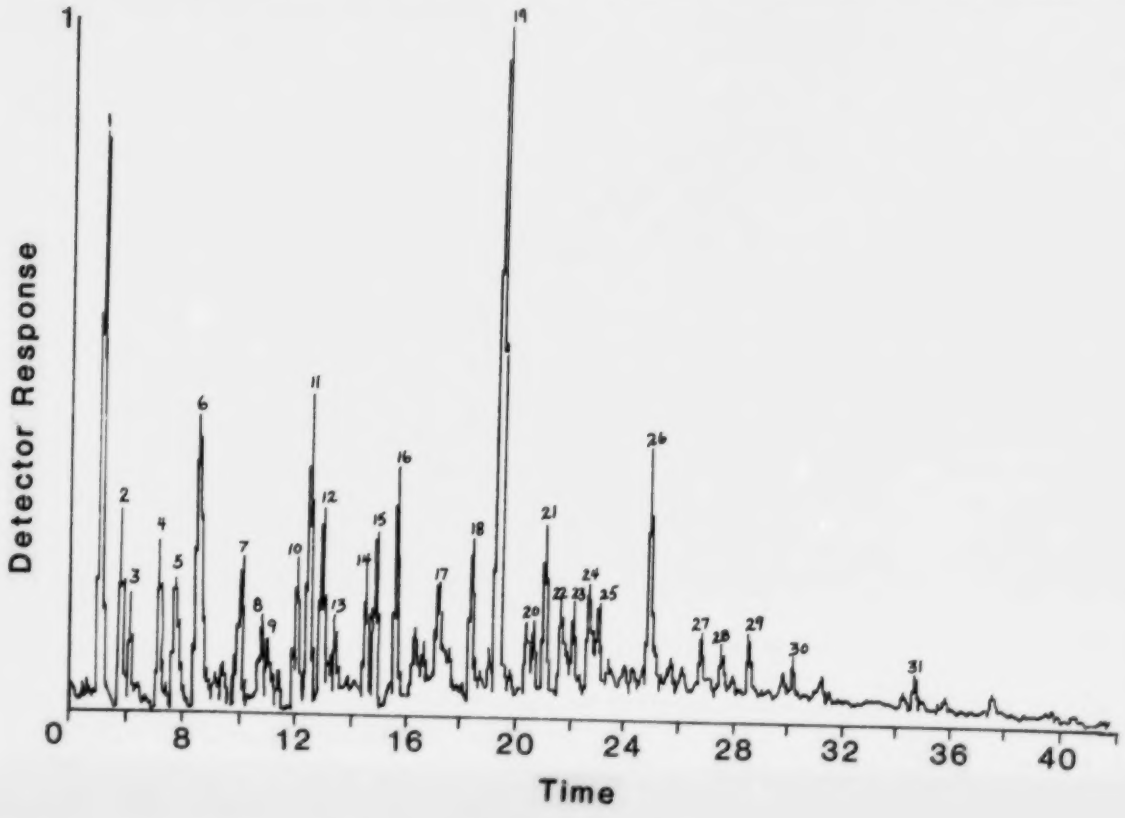
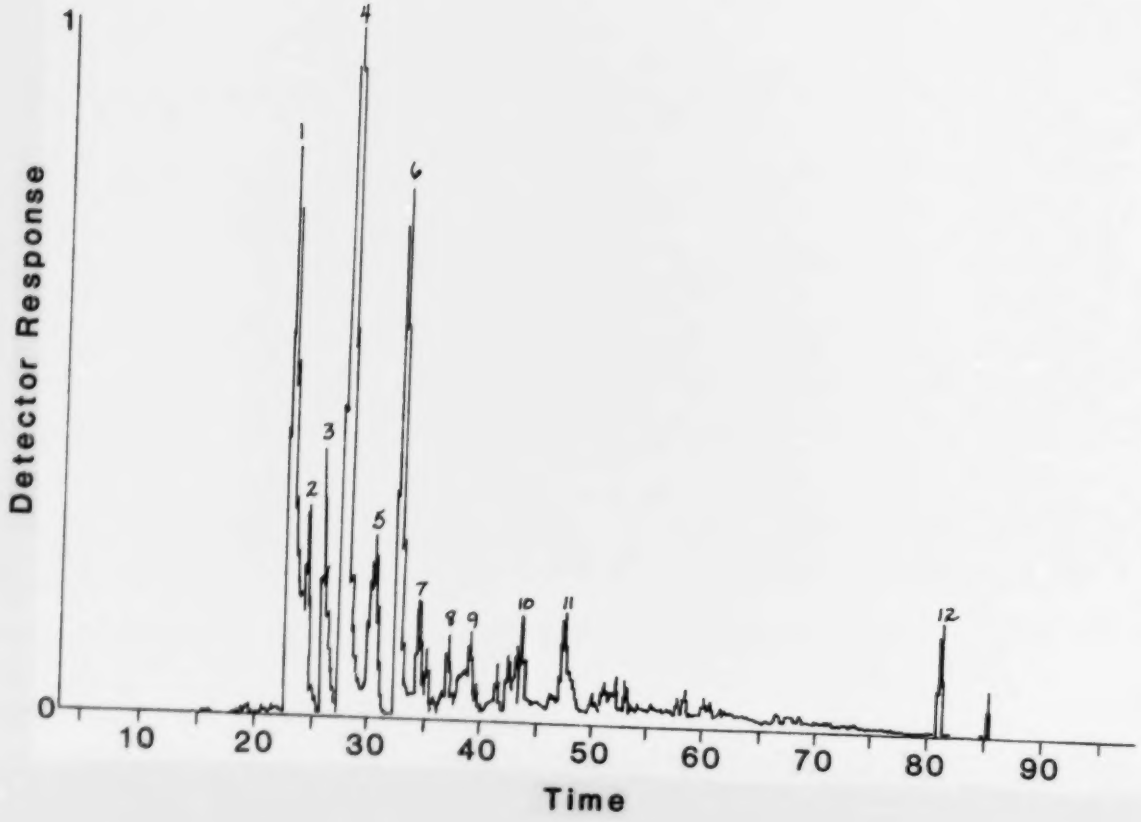


FIGURE 17
GOP-6 PCS WATER (Acid Extract)

Peak No	Compound
1	phenol
2	2-methoxyphenol
3	2,6-dimethyl or ethyl substituted phenol
4	methyl substituted phenol
5	dimethyl substituted phenol
6	ethyl or dimethyl substituted phenol
7	1-(2,4-dihydroxyphenyl)ethanone
8	methylethyl or propyl substituted phenol
9	3,4-dimethoxyphenol
10	sulfur containing hydrocarbon
11	hydroxy-methoxyphenyl substituted ethanone
12	hexanedioic acid ester



Compressor Knockout Liquid---

Figure 18 shows the GC/MS scan of the liquid condensed from the gas stream downstream from the AGRS feed gas compressor. As can be seen, this liquid contains fairly volatile compounds, primarily benzene, toluene, xylene, and other substituted benzenes. It is interesting to note that substantial amounts of these compounds are still in the gas stream at this point in the process. Only traces of compounds heavier than C_{10} compounds were found, indicating that most of the PNA's and other heavy hydrocarbons were effectively removed by the scrubbing, cooling, and filtering operations of the PCS system.

Tar---

Tables 12 and 13 present the results of an analysis of the tar collected from the sample train cold trap during the steady state portion of run GOP-4B. Also shown for comparison is the analysis for the New Mexico coal run, GO-78. Both analyses were done by the Research Triangle Institute, Research Triangle Park, N. C. Generally, the tar from the peat gasification contained more acidic compounds and fewer of the high molecular weight PNA compounds, although the differences were not great. The peat tar contained very little organic sulfur compounds in contrast to the coal tar. Concentrations of sulfur compounds in the peat tar were too low for analysis.

TABLE 12
TAR PARTITION RESULTS
Tar Sample from Sample Train Cold Trap

	GO-78 Wt %	GOP-4B Wt %
Acids	17.29	22.5
Bases	6.05	4.4
TOTAL NEUTRALS	76.66	
Non polar	11.53	16.6
Polynuclear Aromatics	26.85	15.8
Polar Neutrals	16.45	20.8
Cyclohexane Insolubles	21.83	2.6

FIGURE 18
GC/MS ANALYSIS OF COMPRESSOR KNOCKOUT LIQUID
From Combined Peat Runs GOP-1 through GOP-6

Peak No	Compound	Peak No	Compound
1	hexene or methyl substituted pentene	7	ethylbenzene
2	benzene	8	xylene
3	heptene or other C_7 hydrocarbon	9	substituted benzene
4	toluene	10	nonene
5	octene or other C_8 hydrocarbon	11	nonane
6	octane	12	methyl ethyl substituted benzene
		13	decene

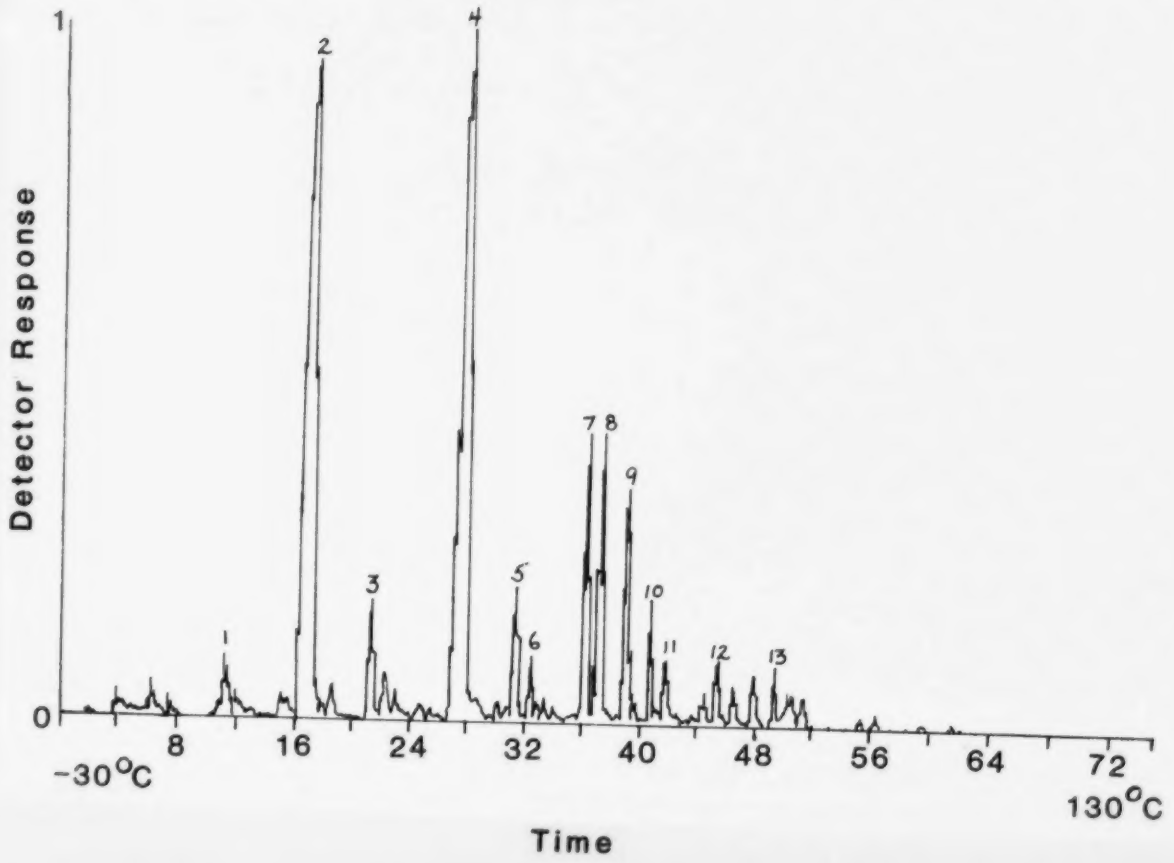


TABLE 13
CAPILLARY GC TAR ANALYSES
Tar Samples from Sample Train Cold Trap

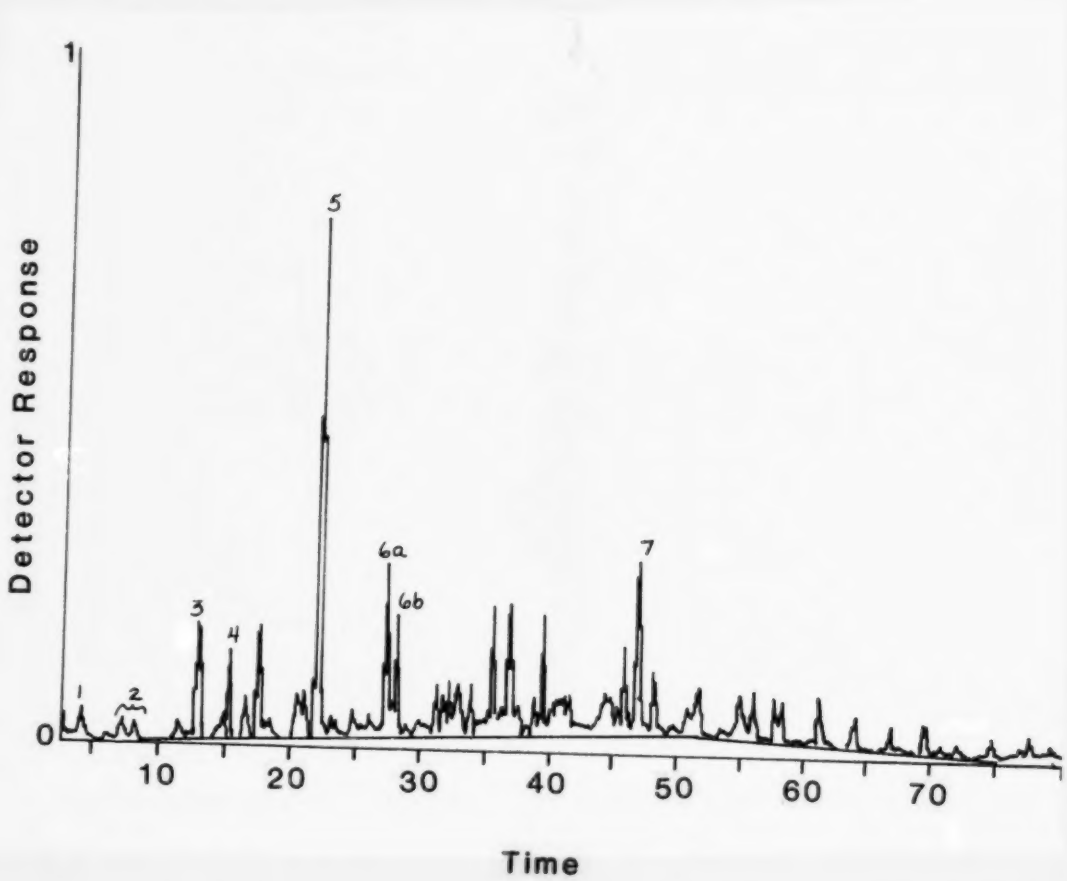
Compound	GO-78 Wt %	GOP-4B Wt %
Phenol	----	4.93
Cresols	----	6.14
Xylenols	----	4.40
Napththalene	2.10	6.06
Benzothiophene	0.08	0.02
Quinoline	0.13	0.20
2-Methylnaphthalene	0.97	3.17
1-Methylnaphthalene	0.81	1.22
Biphenyl	0.28	0.74
Acenaphthylene	0.60	0.80
Acenaphthene	0.26	1.83
Dibenzofuran	0.53	2.58
Fluorene	0.43	1.74
Dibenzothiophene	0.09	----
Phenanthrene	0.47	1.70
Anthracene	0.49	0.56
Fluoranthene	0.23	0.53
Pyrene	0.17	0.14
Benzo(a)anthracene	0.05	0.07
Chrysene	0.04	0.04
Triphenylene	0.02	0.02
Benzo(b)Fluoranthene	0.013	
Benzo(k)Fluoranthene	0.007	
Benzo(e)Pyrene	0.007	0.50 Total of 5 Ring Compounds
Benzo(a)Pyrene	0.015	
Perylene	0.01	
Total Wt %	7.802	37.39

The analysis that produced the results shown in Table 13 was specifically for the compounds listed and did not attempt to identify other compounds present in the tar. Figure 19 shows a GC/MS scan of the tar from GOP-4B, made on the facility at N. C. State University. In addition to several of the compounds shown in Table 13, many other compounds are seen to be present in the tar. Future work will include attempts to identify many of these.

The production rate of tar can also be determined from sample train cold trap measurements. For run GO-78, the tar rate was 1.55 kg/hr (3.41 lb/hr), while the rate was 1.48 kg/hr (3.26 lb/hr) for run GOP-4B. Production rates were 83 g tar/kg feed for coal, and 56 g/kg for peat.

FIGURE 19
GC/MS ANALYSIS OF GOP-4B COLD TRAP TAR SAMPLE

Peak No	Compound
1	toluene
2(a,b)	ethylbenzenes
3	phenol
4	propanoylbenzene
5	napthalene
6(a,b)	methylnapthalenes
7	phenanthrene



Trace Metal Analysis

A detailed trace metal analysis for arsenic, lead, and mercury was carried out for run GOP-4B and the results are shown in Table 14. The analyses done on these three metals for run GO-78 are also shown for comparison. Most of the trace metal mass balance closures are below 100%, indicating the strong possibility that substantial amounts of these volatile metals are present in the gas stream and escaped detection. Methods are currently under development to trap and analyze for these metals in the gas stream, but gas stream analyses were not attempted for the peat runs.

Although no definite conclusions can be drawn from the results of one run, it can be seen that for all three metals, the peat char was depleted of these metals to a greater extent than the coal char, though the gasification conditions and the final carbon conversion in both runs were almost the same. One possible explanation is that the metals are not as strongly bound to the organic matrix in peat as they are in coal, and hence are more easily devolatilized. Additional data, however, are needed before any firm conclusions can be reached.

The cyclone dust from peat gasification was similarly enriched in all three metals to a larger degree than in coal gasification. A possible explanation for the relatively large amounts of these metal elements in the cyclone dust is that they are volatilized in the gasifier and then tend to condense on the particulates collected in the cyclone separator.

A somewhat surprising result of this analysis is the relatively high concentration of mercury in the peat feed material.

TABLE 14
MASS BALANCE RESULTS FOR THE TRACE METALS
ARSENIC, LEAD, AND MERCURY

	GOP-4B		GO-78	
	ppm	mg/hr	ppm	mg/hr
Arsenic				
Input:				
Feed	1.9	50	3.5	66
Output:				
Char	2.1	10	3.6	22
Cyclone dust	12.0	37	5.8	10
Cold Trap:				
Tar	2.2	4	2.4	4
Solids	*	*	7.1	1
Water	*	*	0.19	4
Gas				
Total		51		42
Mass Balance Closure % of Input		102		62
Lead				
Input:				
Feed	6.4	167	7.1	132
Output:				
Char	3.3	16	4.8	29
Cyclone dust	20.0	62	5.7	10
Cold Trap:				
Tar	6.1	10	2.0	3
Solids	41.0	12	15.6	2
Water	*	*	0.01	<1
Gas				
Total		100		44
Mass Balance Closure % of Input		60		33
Mercury				
Input:				
Feed	0.52	13.8	0.058	1.1
Output:				
Char	0.29	1.4	0.048	0.29
Cyclone dust	0.064	1.98	0.054	0.09
Cold Trap:				
Tar	0.79	1.37	1.47	2.36
Solids	8.1	2.42	5.33	0.67
Water	*	*	0.003	0.08
Gas	*	*	0.267+	0.25
Total		7.17		3.74
Mass Balance Closure % of Input		52		346

* Insufficient data for determination

\+ ug/scf

ACID GAS REMOVAL SYSTEM OPERATION

The purpose of this part of the study was to evaluate the environmental consequences of the use of methanol as an acid gas removal solvent for gases generated by peat gasification. Although the Rectisol process, which uses refrigerated methanol, has been used by the Lurgi Corporation since the early 1950's, little is known about the fate of several environmentally significant compounds after they have entered the gas cleaning unit. Under carefully controlled conditions, measurements were made to determine how these compounds distribute through the acid gas removal system for different process situations. A complete discussion of the operation of the acid gas removal system during the study of the gasification of the New Mexico coal was given in Volume III of this report series, Ferrell et al., (1982), and by Kelly, (1982). Very little additional can be said about the operation of the AGRS for the runs discussed here, except that it operated well, and indicated no unusual problems when used for cleaning gas produced from peat gasification.

Table 15 lists the most important characteristics of the absorber and stripper columns as used for the peat gasifications runs.

TABLE 15
COLUMN SPECIFICATIONS AND OPERATING RANGES FOR METHANOL

	Absorber	Stripper
Total Packed Height	14.2 Feet	21.3 Feet
Column Diameter	5 Inches	6 Inches
No. of Packed Sections	2	3
Packing Type	Ceramic Intalox Saddles	Ceramic Intalox Saddles
Operating Temperature	-40 To 0°F	-10 To 60°F
Operating Pressure	350-450 psig	5-25 psig
Liquid Flow Rate	0.70-1.40 gpm	0.70-1.40 gpm
Gas Flow Rate	10-20 scfm	2-10 scfm

A summary of the operating conditions for the two integrated runs made with peat feed were given in Table 3, and complete mass balances are given in Appendix D. Two different conditions for the absorber were used to provide two separate tests of the mathematical model being developed for the absorber operation. The first of the two runs, AMIP-2 (GOP-4B), was made at an intermediate operating condition in the absorber. The absorber pressure was 100 psig below the maximum possible (450 psig), the solvent flow was set at 0.87 gpm, and the absorber solvent inlet temperature was about 20°F higher

than the lowest possible value. For the second run, AMIP-3 (GOP-6), the absorber pressure was set at 450 psig and the solvent flow and temperature were set for the best possible acid gas removal conditions.

In both cases the overall mass balances and the balances for the major compounds were excellent, indicating that there were no major errors in either the flow measurements or the analyses of the input and output gas streams. The mass balances for the sulfur gases and some of the higher molecular weight hydrocarbons are not entirely satisfactory, and illustrates the difficulty of good mass balances for compounds present in low concentrations.

The complete compound analyses for the input and output gas streams for the acid gas removal system for the two integrated runs are given in Appendix B. Under both absorber conditions, the acid gases, CO_2 and H_2S, were removed to very low levels. The lower solvent inlet temperature, higher solvent flow rate, and higher absorber pressure used in the second run gave somewhat higher removal efficiencies. While the distribution of the major acid gases (H_2S, COS, and CO_2) in the AGRS can probably be predicted from phase equilibria information and engineering calculations, the low levels of trace compounds in the gas fed to the AGRS make predictive results questionable and experimental data a necessity.

The most critical factor in removing compounds to very low concentrations in the absorber is the effectivness of the stripping operation in removing the compounds from the solvent. From the previous work on coal, it was shown that the small concentrations of H_2S and COS in the absorber exit gas were due to inadequate stripping of the methanol. In a well designed system, the acid gases could be removed to any level desired by proper configuration of the flashing and stripping operations.

One of the features of gases produced from coal or peat is the relatively high levels of COS produced with the H_2S. The conversion of COS to H_2S before it enters the acid gas removal system is necessary in many proposed processes for treating these gases because of the difficulty of removing COS to required levels. Chemical solvent systems often form degradation products with COS and CS_2 while some physical solvent systems cannot be operated at sufficiently low temperatures to remove COS to low enough levels. From the data collected in this study, and in the previous studies on coal, it appears that refrigerated methanol is effective in removing COS, and no unusual solubility characteristics are evident.

EMISSIONS FROM THE ACID GAS REMOVAL SYSTEM

Neither of the two integrated runs made in this study were long enough to be sure that the minor compounds (compounds present in the gas feed in low concentrations), had reached a steady state concentration in the methanol solvent. For this reason, the composition of the exit gas streams from the

AGRS were also probably not at steady state values for the minor compounds. Even so, some general conclusions from the data shown in Appendix B can be made.

Trace Sulfur Compounds

In addition to H_2S and COS, several other sulfur compounds present in the gas fed to the AGRS must be removed. Inspection of tables B-4 and B-5 (Appendix B) shows the distribution of several of these compounds in the AGRS. Due to the short duration of these runs, the concentrations of the trace sulfur gases in the flash gas and the acid gas are probably not typical of steady state operation, since they are not completely accounted for in the flash and acid gas streams. This can be seen for methyl mercaptan and thiophene which are present in relatively high levels in the feed gas. These compounds will accumulate in the solvent and eventually leave the system in one of three exit streams: sweet gas, flash gas, or acid gas. Because most sulfur recovery systems cannot treat mercaptans and thiophene, they will present emission problems if some additional method of treating these gases is not used. Since the amount of sulfur gases from peat gasification is small, this is not likely to be a control problem. However, if these compounds appear in the the sweet gas, they are likely to affect any downstream catalytic processes adversely. The presence of small amounts of these compounds in the sweet gas stream should present no problem if the gas is to be burned for immediate use, because the sulfur in these compounds will be converted to SO_2.

Aliphatic Hydrocarbons

Over the range of conditions studied here, the most significant point to be made about the distribution of aliphatic hydrocarbons is their presence in significant quantities in the flash and acid gases. Since the gasification of peat tends to produce more of these compounds than coal, the problem may be of some importance for the design of gas cleaning systems for peat gasification.

Although flashing of the methanol down to atmospheric pressure prior to stripping would release most of the hydrocarbons, the CO_2-rich flash gas would still contain substantial amounts of several hydrocarbon species. Since it is unlikely that all of the aliphatic hydrocarbons will appear in the sweet gas, as evidenced by the data collected here, additional treatment may be necessary to prevent their eventual appearance in a vent stream.

There appears to be no unusual pattern of distribution of aliphatic hydrocarbons in the AGRS, and they tend to distribute as would be expected from a Henry's law relationship.

Aromatic Hydrocarbons

Because of the relatively large amounts of aromatic hydrocarbons produced during peat gasification, the potential for environmental problems is significant. These compounds, which range from benzene to polynuclear species of many forms, must be prevented from escaping from the gas cleaning process for obvious reasons. Their distribution throughout the gas cleaning process is, therefore, of some concern.

The simpler aromatics, benzene, toluene, and xylene, typically make up 0.1% (by volume) of the gas stream entering the AGRS. Of interest is the fact that these compounds tend to accumulate in the recirculating solvent after they have been removed from the entering gas stream. For the runs discussed here, even though steady state was probably not reached for these compounds, the concentrations in the acid gas stream are fairly high.

Methanol Analysis

In order to identify the various hydrocarbon species that accumulate in the methanol, a sample of the methanol leaving the stripper was taken for GOP-4B. The sample was analyzed by HPLC as described in the section on analytical methods. At this time the HPLC had not yet been calibrated for quantitative analysis, but the relative amounts of the major compounds in the methanol can be seen in the chromatogram shown as Figure 20. While the higher molecular weight compounds shown in the chromatogram are not identified, it is very unlikely that any multi-ring aromatic compounds are present.

For comparison, a chromatogram for a recent run with New Mexico coal, obtained with the same HPLC program is shown in Figure 21. The two are very similar.

Figure 20

GOP-4B
STRIPPER EXIT METHANOL

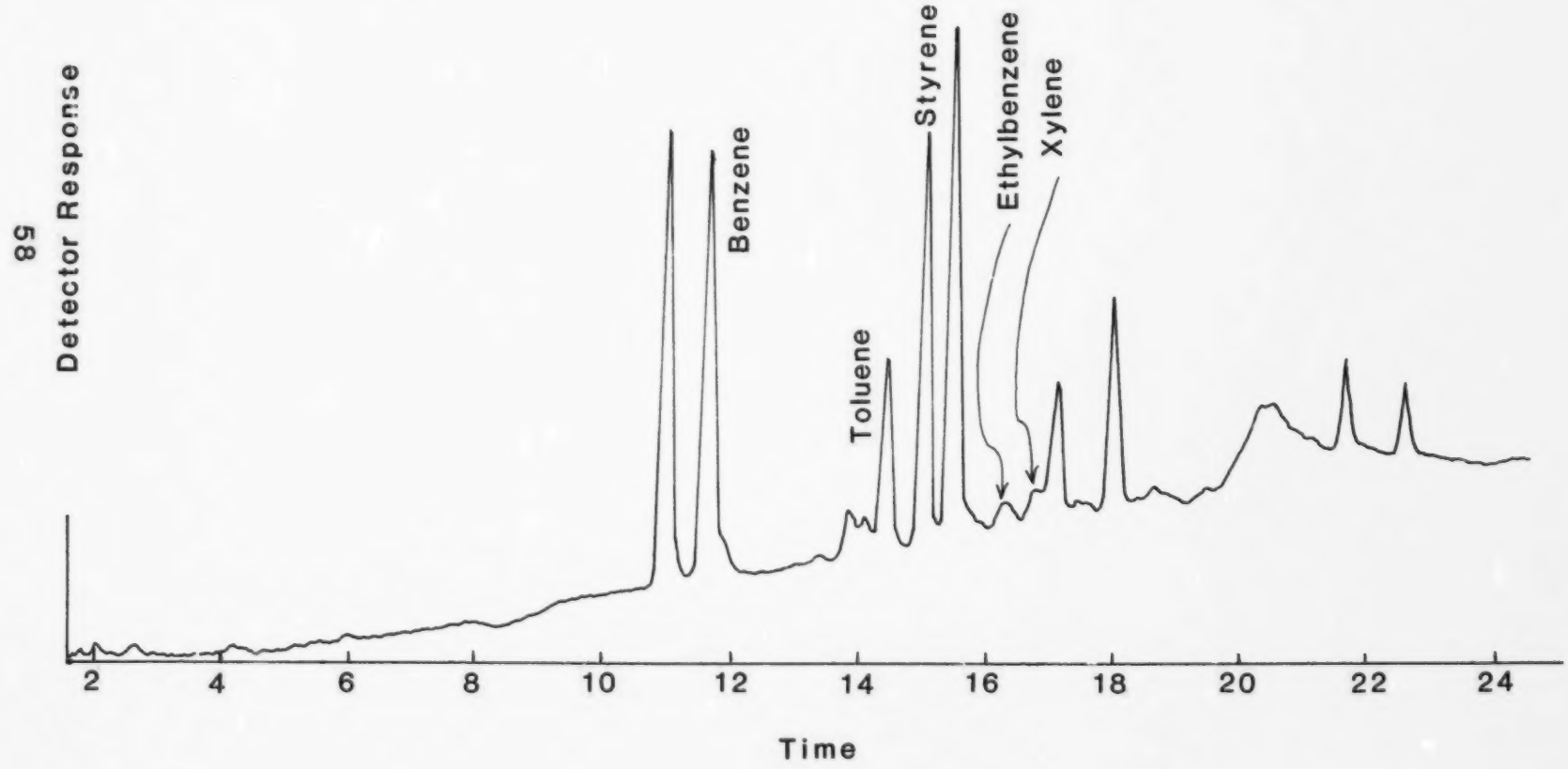
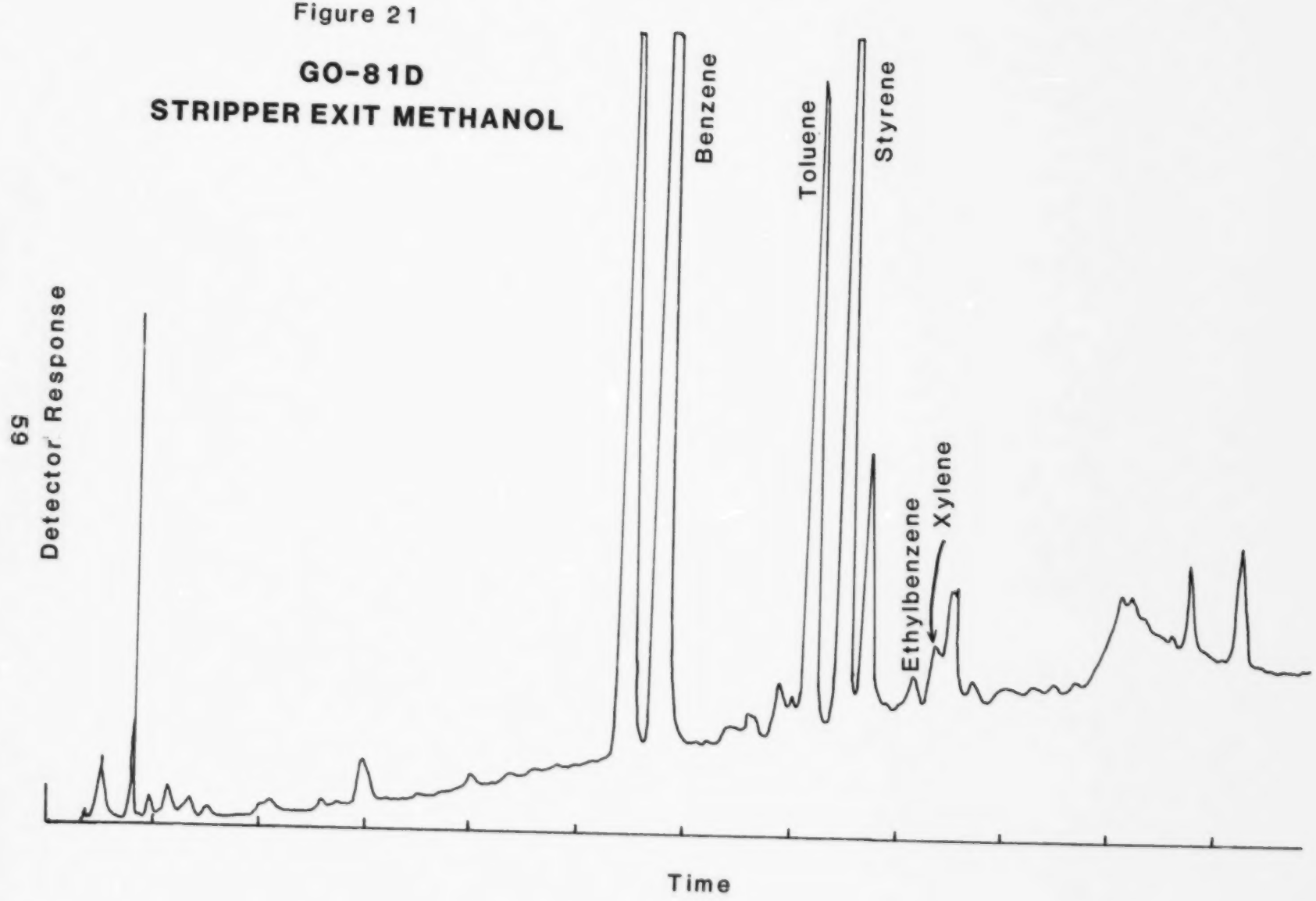


Figure 21


GO-81D
STRIPPER EXIT METHANOL
69
Detector Response
Benzene
Toluene
Styrene
Ethylbenzene
Xylene
Time

SUMMARY AND CONCLUSIONS

Five gasifier runs were completed successfully using a feed of North Carolina peat. The first three of these runs made use of the gasifier-PCS system only, and were used to determine optimum operating conditions for the gasifier. The last two were integrated and used the gasifier make gas as feed to the acid gas removal system.

The peat used in this experimental program was obtained from First Colony Farms, Inc., from an operating site in Washington County, North Carolina. The milled peat was a mixture of fibrous material, small pieces of wood, particles of solid peat, and a fairly large amount of fine material. The moisture content of the peat as received was approximately 50%. The peat was prepared for gasification by screening through 1/4 inch hardware cloth and air dried at room temperature to a moisture content of about 25%. The peat was fed to the gasifier without any further preparation.

For most of the runs the fluidized bed gasifier worked very well. With the top feed arrangement, most of the gas production took place in the zone above the fluidized bed by devolatilization. The gasifier acted as a two stage gasifier with a small fluidized bed of peat char in the lower zone and a devolatilization zone in the region above the bed. As a result of the first two runs, the best gasifier operating condition was determined to be a feed rate of approximately 30 kg/hr (65 lb/hr) and a fluidized bed temperature of 900°C (1650°F). Under these conditions the gasifier produced a make gas flow of approximately 0.5 standard cubic meter of dry gas per minute (18 SCFM).

It is useful to compare the results of the gasification of North Carolina peat with the gasification of the New Mexico subbituminous coal carried out with the pilot plant facility prior to the runs with peat. In general, lower operating temperatures were used in peat gasification than in the gasification of the New Mexico coal, and the product gas yields obtained from both were of similar magnitude. The higher feed rates used in the peat runs were probably a major factor in this result, but the similar product rates at lower temperatures may also reflect a greater reactivity of the peat relative to the coal.

Proximate and ultimate analyses of the feed peat, the solid samples collected from the cyclone, and the spent char were as expected. The spent char was found to have a relatively high carbon content as a result of the very low ash content of the peat. Overall carbon conversion was satisfactory

and very little spent char was formed.

A comparison of the gas analyses for the peat runs with those for the New Mexico coal show no major differences in gas composition except for the sulfur species. This is undoubtedly due to the difference in the sulfur content of the feed materials, since the ratio of total sulfur in the product gases is the same as the ratio of sulfur in the feed materials. The peat gas had slightly more CO and CO_2, while the coal gas had slightly more methane. The higher concentrations of methane from the New Mexico coal, compared to peat, is consistent with the results of a series of independent devolatilization studies on these materials.

Production rates, calculated as grams produced per kilogram of peat or coal fed, indicate that in general, hydrocarbon production is of similar magnitude in both coal and peat gasification, while sulfur production is much less for peat. The peat gas had a greater benzene production rate than the coal, while the methane production rate was greater for the coal.

With the exception of dissolved carbon (Carbon, COD, TOC, and TVC), the waste water analyses for coal and peat are nearly the same. The dissolved carbon content for the peat runs was quite high and was mostly in the form of phenols. This is consistent with other results which indicate that the gasification of peat produces relatively greater amounts of phenols and other acidic compounds than the gasification of coal. An analysis of the waste water by GC/MS also showed a higher concentration of acidic compounds and a lower concentration of compounds from the base/neutral extract. Compared to previous results from coal gasification, the waste water from peat gasification contains less polynuclear aromatic compounds (PNA's), and very few PNA's of high molecular weight.

A GC/MS analysis of the liquid condensed from the gas stream downstream from the AGRS sour gas feed compressor contains only the more volatile trace organic compounds, primarily benzene, toluene, xylene, and other substituted benzenes. It is interesting to note that substantial amounts of these compounds are still in the gas stream at this point in the process. Only traces of compounds heavier than C_{10} compounds were found, indicating that most of the PNA's and other heavy hydrocarbons were effectively removed by the scrubbing, cooling, and filtering operations of the PCS system.

Samples of tar collected from the sample train cold trap were analyzed by the Research Triangle Institute, Research Triangle Park, N. C. Generally, the tar from the peat gasification contained more acidic compounds and fewer of the high molecular weight PNA compounds, although the differences were not great. The peat tar contained very few organic sulfur compounds in contrast to the coal tar. Concentrations of sulfur compounds in the peat tar were too low for analysis.

A detailed trace metal analysis for arsenic, lead, and mercury was carried out for run GOP-4B. Most of the trace metal mass balance closures were below 100%, indicating the strong possibility that substantial amounts of these volatile metals were present in the gas stream and escaped

detection. Although no definite conclusions can be drawn from the results of one run, the peat char was depleted of these elements to a greater extent than the coal char. One possible explanation is that the metals are not as strongly bound to the organic matrix in peat as they are in coal, and hence are more easily devolatilized. A somewhat surprising result is the relatively high concentration of mercury in the peat feed material.

One of the major purposes of this study was to evaluate the environmental consequences of the use of methanol as an acid gas removal solvent for gases generated by peat gasification. In this study, the AGRS operated well, and indicated no unusual problems when used for cleaning gas produced from peat gasification.

For both of the AGRS runs made, the overall mass balances and the balances for the major compounds were excellent, indicating that there were no major errors in either the flow measurements or the analyses of the input and output gas streams. Under both absorber conditions used, the acid gases, CO_2 and H_2S, were removed to very low levels, with the lower solvent inlet temperature, higher solvent flow rate, and higher absorber pressure used in the second run giving somewhat higher removal efficiencies.

One of the features of gases produced from coal or peat is the high levels of COS produced with the H_2S. The conversion of COS to H_2S before it enters the acid gas removal system is necessary in many proposed processes for treating these gases because of the difficulty of removing COS to required levels. From the data collected in this study, and in the previous studies on coal, it appears that refrigerated methanol is effective in removing COS, and no unusual solubility characteristics are evident.

Due to the short duration of the runs using the AGRS, the concentrations of the trace sulfur gases in the flash gas and the acid gas are probably not typical of steady state operation, since they are not completely accounted for in the flash and acid gas streams. These compounds will accumulate in the solvent and eventually leave the system in one of three exit streams: sweet gas, flash gas, or acid gas, along with the H_2S and COS. Since the amount of sulfur gases from peat gasification is small, this problem should have several acceptable solutions.

If the product gas from peat gasification is to be used in a catalytic process, such as the manufacture of high Btu gas or methyl alcohol, then an acid gas removal system of some kind will be necessary to prevent sulfur from reaching the downstream catalytic processes. The sulfur gas rich streams, such as the flash gas and the acid gas from the AGRS, could probably be safely incinerated, converting the sulfur gases to SO_2. Current regulations limit SO_2 emissions from a coal-fired or peat-fired boiler to 1.2 pounds of SO_2 per million Btu of heat generated. If this regulation can be applied to a peat gasification facility, the total sulfur emmitted after incineration would be low enough to satisfy all regulatory requirements (Peat at 0.2 % sulfur would result in an emission of approximately 0.4 pounds SO_2 per million Btu of heating value of the peat, assuming that all of the sulfur in the peat was gasified).

If the product gas from peat gasification is to be used directly in a combustion process, then the low sulfur content of the peat feed should make the requirement for an acid gas removal system unnecessary. In either case, the low sulfur content of the peat would probable make sulfur recovery processes uneconomical.

Over the range of conditions studied here, the most significant point to be made about the distribution of aliphatic hydrocarbons is their presence in significant quantities in the flash and acid gases. Since the gasification of peat tends to produce more of these compounds than coal, the problem may be of some importance for the design of gas cleaning systems for peat gasification. If the flash and acid gases are incinerated, there should be no significant emission problems associated with hydrocarbons.

Because of the relatively large amounts of aromatic hydrocarbons produced during peat gasification, the potential for environmental problems exists. These compounds, which range from benzene to polynuclear species of many forms, must be prevented from escaping from the gas cleaning process for obvious reasons. Their distribution throughout the gas cleaning process is, therefore, important. Once again, incineration of the vent gases should be a solution to the emission of these hydrocarbons.

In order to identify the various hydrocarbon species that accumulate in the methanol, a sample of the methanol leaving the stripper was analyzed by HPLC. The only compounnds identified were benzene, toluene, xylenes, and other substituted benzenes. No PNA's or other multi-ring aromatic compounds were found, indicating that the accumulation of organic compounds in the methanol solvent should not be a serious problem. Simple distillation of the solvent should serve to recover pure methanol.

Several general conclusions can be drawn from this research project. The first is that the gasification of North Carolina peat produces a make gas almost identical in character and composition to that from the gasification of a subbituminous coal with the major differences being lower concentrations of sulfur compounds, due to the low sulfur content of the peat, and higher concentrations of the acidic organic compounds such as phenols.

A second general conclusion is that the raw gas cleaning process, the PCS system in our facility, consisting of a cyclone separator, a venturi scrubber, filters, coolers, and demisters was effective in removing almost all of the nonvolatile compounds from the make gas stream. For all practical purposes, no hydrocarbons heavier than substituted benzenes entered the acid gas removal system. Those compounds which did accumulate in the chilled methanol solvent would appear to be easily removed by distillation.

Three general areas of potential environmental concern are apparent from the above summary of the findings of this research project. These are the waste gas streams from the AGRS, the condensed organic compounds such as the tars and oils from the PCS system, and the waste water from the PCS system. The solids streams from the process are small in volume, and do not appear to be an environmental problem. If an acid gas removal system such as the one

used for this project is employed for cleaning the gas produced from peat gasification, the waste gas streams would most likely have to be treated; by incineration for example.

The fluidized bed gasification of peat can be expected to produce relatively large quantities of heavy organic compounds which will appear as tars, and relatively large quantities of water soluble organic compounds, such as phenols, which will appear in the waste water. Both of these are potential environmental problems, and would have to be dealt with; however, both are also a potential source of valuable organic chemicals.

Other types of gasifiers, especially those that operate at higher temperatures such as the entrained bed gasifiers, will produce less of the trace sulfur and hydrocarbon compounds and less of the heavy hydrocarbons such as tars and oils. The sulfur in the peat feed will, however, be converted primarily to H_2S and COS, and will still have to be removed if the product gas is to be converted to other chemicals by catalytic processes. The comments made earlier concerning AGRS vent gas emissions would still apply. In addition, during startup and shutdown of entrained bed gasifiers, many of the emission problems are similar to those of the fluidized bed and fixed bed gasifiers.

The fixed bed types of gasifiers could be expected to produce approximately the same quality of gas as the fluidized bed gasifier, and approximately the same mix of trace sulfur compounds, trace hydrocarbon compounds, and tars and oils. The potential environmental problems would therefore be similar.

A final, general conclusion from this work is that North Carolina peat is an excellent feed material for steam-oxygen gasification, and its use as a gasifier feed presents no unusual problems. The economics of peat gasification would appear to be especially attractive when the gasification facility is located very near to the source of peat and peat transportation costs are minimized. The product gas could be used as a low or medium Btu fuel gas with a minimum of gas cleaning, or could be upgraded to a high Btu gas by catalytic methanation. The product gas would also make an excellent feed stock for the production of a variety of of chemicals by catalytic processes. In both of the latter cases, in addition to the raw gas cleaning, some form of acid gas removal system would have to be used prior to catalytic processing.

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APPENDIX A
NOTES FOR RUN GOP-1

GOP-1
JUNE 16, 1981

15:17:26 LEAK TEST FOR FIRST RUN WITH NORTH CAROLINA PEAT
LEAK RATE AT 30 PSIG IS 0.14 SCFM

15:20:32 THIS RATE IS PRETTY HIGH, WILL GO AHEAD AND CHECK AT 100 PSIG

15:45:13 LEAK RATE AT 100 PSIG IS 0.59 SCFM, HIGHER THAN WE
WOULD LIKE, BUT WE WILL GO WITH IT.

RUN GOP-1
JUNE 17, 1981

07:12:04 TURNED HEATERS ON AND STARTED PRESURIZATION

07:15:30 STARTUP PROCEDURES TO BE THE SAME AS FOR THE
LAST FEW RUNS WITH COAL.
25 LBS OF CHAR LOADED INTO GASIFIER

07:18:32

LEAD ENGINEER:	GANESAN
CHIEF OPERATOR:	FOLSOM
GRAV WATER:	HUBICK
SAMPLING:	LARRY HAMEL QUARTET
FACULTY:	FERRELL

07:37:50 REACHED REACTOR OPERATING PRESSURE

08:02:08 AOV-117 WAS LEFT IN CLOSED POSITION, AND WHEN SYSTEM
WENT INTO AUTOMATIC, IT WENT TO FAILED POSITION,
OPENED, AND BYPASSED THE NITROGEN
FLOW CONTROL VALVE. LOTS OF FLOW THROUGH THE SYSTEM
FOR ABOUT 5 MINUTES.

08:03:42 ALSO SX-1 WAS LEFT CLOSED AND WE GOT A HIGH OXYGEN
ALARM

08:07:31 THINK THE SYSTEM RECOVERED OK

08:35:25 START PEAT FEED AT ABOUT 25 RPM
TEMPERATURES 5 INCH = 519, 10 INCH = 511

08:47:06	CYCLONE INLET TEMPERATURE DROPPED WHEN PEAT FEED STARTED.
09:10:05	TOTAL COUNTS 1038 TEMPS 551 540 459 DPS 0, 0, 0, CYCLONE=1.8 VENTURI=1 FILTER=2.2
09:13:47	WILL TAKE GAS SAMPLE AT PCS BEFORE OXYGEN
09:21:53	TEMP DIPS TEMPS 507 499 TOTAL COUNTS=1400
09:37:23	1852 TOTAL COUNTS
09:47:56	NOT MUCH HAPPENING, WILL INCREASE FEED RATE TO 35-40 RPM
09:51:02	FLARE IS OUT, PROBABLY WENT OUT WHEN BIG NITROGEN FLOW UPSET
09:53:22	BIG INCREASE IN 5 INCH TOTAL COUNTS 2415
09:59:17	TAKING GAS SAMPLE AT SX-1 FOR ANALYSIS ON CARLE
10:02:21	STARTING INCREASE IN 10 INCH COUNTS 2775
10:03:11	START DPT-201 COUNTS 2825
10:04:14	SET PEAT FEED AT ABOUT 45 RPM
10:04:34	START OXYGEN
10:22:45	TAKING GAS SAMPLE AT SX-1
10:25:48	REACHED BED LEVEL
10:27:52	SEEMED TO HAVE REACHED BED LEVEL BUT HAVE VERY LOW DPT-201
10:33:42	CUT FEED RATE BACK TO 45 WILL START STEAM AT ABOUT 15 LB/HR
10:35:01	STEAM ON
10:50:49	START SAMPLE TRAIN
10:53:31	THINK BED LEVEL IS ABOUT 10 INCHES BECAUSE OF NO DPT-201 AND TEMPERATURES. WILL START TO INCREASE PEAT FEED UP TO 50 RPM NOW TURNED FLARE ON AGAIN
11:09:04	TOOK PCS SAMPLE BROUGHT STEAM UP TO 58 LB/HR AND PUT CONTROLLER IN CASCADE

11:13:39	INCREASED FEED TO 70 RPM
11:18:34	INCREASED FEED RATE TO 80 RPM
11:41:16	TOOK GAS SAMPLE AT SAMPLE TRAIN
11:41:31	AREA ALARM ON SMALL AMOUNT OF SMOKE FROM INSULATION AT CYCLONE, SNIFFER FOUND NO CO
11:43:44	WILL DECREASE STEAM FLOW TO ABOUT 45 LB/HR
11:50:11	STARTED COLD TRAP
12:39:35	TURNED COLD TRAP OFF
13:08:05	TAKING AT SAMPLE TRAIN BOMBS 23 AND 5G AT THE PCS BOMBS 22 AND 3G
13:08:49	AFTER SAMPLES ARE CONFIRMED, WILL CHANGE CONDITIONS
13:12:04	INCREASING FEED RATE TO 95 RPM
13:17:08	WILL CHANGE SEEAM FEED RATE TO 35 LB/HR
13:33:57	BOMB 26 TAKEN AT SAMPLE TRAIN
13:39:28	DECREASED NITROGEN FLOW FROM 1.9 TO 1.3 BY FOOLING AROUND WITH THE FLOW CONTROL VALVE IN MANUAL MADE SOME CHANGE IN REACTOR CONDITIONS. VERY SENSITIVE SYSTEM
14:06:21	TAKING SAMPLE TRAIN SAMPLES ABOUT EVERY HALF HOUR
14:40:13	OCCASIONAL VERY LARGE (100) VARIATION IN 5 AND 10 INCH TEMPERATURES
15:05:53	TAKING FINAL SET OF GAS SAMPLES SAMPLE TRAIN BOMBS 25 AND 11G PCS BOMBS 24 AND 6G
15:06:55	IT APPEARS THAT THE PEAT FEED IS NOT STEADY, OCCASIONALLY A LARGER FEED GOES INTO THE REACTOR, THE GAS RATE GOES UP, THE OXYGEN GOES UP, THE BED LEVEL INCREASES ALMOST TO WHERE DPT-201 RESPONDS, AND THE OXYGEN INCREASES. THEN THE THING REVERSES SO THE TEMPERATURES HAVE CYCLED OVER THE LAST HOUR OR SO.
15:11:19	FINISHED SAMPLES
15:12:25	WILL REDUCE TEMPERATURE SETPOINT TO 1650 A DECREASE OF 100 DEGREES

15:14:11	ALSO INCREASE PEAT FEED TO 105
15:23:20	SET POINT IS 1615
15:29:51	LOWER STEAM FEED RATE TO 30 AFTER TAKING A GAS SAMPLE AT SAMPLE TRAIN FOR THE CARLE
15:32:09	STEAM RATE TO 25
15:33:09	NOW HAVE POSITIVE DPT-201
15:47:16	PCS FILTER DP WENT UP TO 30.0 .ALARM WENT OFF. SWITCHED TO NEW FILTER.
16:04:06	TAKING SAMPLE TRAIN SAMPLE
16:05:10	REDUCE TEMPERATURE
16:13:51	LOWERED TEMPERATURE TO ABOUT 1500 ON THE BOTTOM TWO THERMOCOUPLES.
16:22:55	SAMPLE TAKEN AT SAMPLE TRAIN IN STEEL BOMB
16:25:04	SHUT DOWN
16:27:30	WILL TRY AND LEAVE BED IN TILL TOMORROW

APPENDIX B
GAS ANALYSIS DATA FOR ALL PEAT RUNS

TABLE B-1

GAS ANALYSIS SUMMARY FOR GOP-1 13:00 SAMPLE TIME

Species	Sample Train	PCS Exit	Sour Gas	Sweet Gas	Flash Gas	Acid Gas
H_2	24.80	26.67				
CO	12.29	13.86				
CH_4	5.74	5.98				
CO_2	20.92	20.72				
N_2	35.10	31.69				
H_2S	0.0467	0.0506				
COS	0.0025	0.0025				
Thiophene	0.0021	0.0018				
CH_3SH	0.0040	0.0033				
C_2H_5SH	0.0000	0.0000				
CS_2	0.0002	0.0000				
Ethylene	0.4922	0.4561				
Ethane	0.4635	0.4518				
Propylene	0.1196	0.1119				
Propane	0.0296	0.0288				
Butylene	-.----	-.----				
Butane	0.0153	0.0000				
Benzene	0.0527	0.0493				
Toluene	0.0412	0.0393				
Methanol	-.----	-.----				

TABLE B-2
GAS ANALYSIS SUMMARY FOR GOP-1 15:00 SAMPLE TIME

Species	Sample Train	PCS Exit	Sour Gas	Sweet Gas	Flash Gas	Acid Gas
H_2	25.65	26.31				
CO	14.10	13.68				
CO_2	24.32	24.55				
CH_4	6.45	6.18				
N_2	28.17	27.98				
H_2S	0.0512	0.0577				
COS	0.0027	0.0029				
Thiophene	0.0013	0.0022				
CH_3SH	0.0049	0.0052				
C_2H_5SH	0.0000	0.0000				
CS_2	0.0000	0.0000				
Ethylene	0.3968	0.4469				
Ethane	0.4692	0.5073				
Propylene	0.1123	0.1243				
Propane	0.0324	0.0340				
Butylene	-.----	-.----				
Butane	0.0000	0.0000				
Benzene	0.0556	0.0526				
Toluene	0.0398	0.0385				
Methanol	-.----	-.----				

TABLE B-3

GAS ANALYSIS SUMMARY FOR GOP-3 12:00 SAMPLE TIME

Species	Sample Train	PCS Exit	Sour Gas	Sweet Gas	Flash Gas	Acid Gas
H_2	27.21	27.50				
CO	16.90	17.23				
CH_4	6.69	6.64				
CO_2	20.38	20.20				
N_2	27.34	27.00				
H_2S	0.0449	0.0237				
COS	0.0026	0.0023				
Thiophene	0.0012	0.0013				
CH_3SH	0.0022	0.0013				
C_2H_5SH	0.0000	0.0000				
CS_2	0.0000	0.0000				
Ethylene	0.6115	0.5925				
Ethane	0.7624	0.7612				
Propylene	-.----	-.----				
Propane	-.----	-.----				
Butylene	-.----	-.----				
Butane	-.----	-.----				
Benzene	-.----	0.0782				
Toluene	-.----	0.1154				
Methanol	-.----	-.----				

TABLE B-4

GAS ANALYSIS SUMMARY FOR GOP-4B, AMIP-2 11:10-11:30 SAMPLE TIME

Species	Sample Train	PCS Exit	Sour Gas	Sweet Gas	Flash Gas	Acid Gas
H_2	28.40	28.61	28.61	38.47	16.45	0.8882
CO	15.57	15.60	15.60	20.42	18.94	1.3970
CH_4	5.65	5.55	5.55	6.31	9.82	2.52
CO_2	23.17	23.26	23.26	0.32	23.68	67.15
N_2	25.95	25.75	25.75	34.37	28.65	24.71
H_2S	0.0436	0.0480	0.0480	0.0047	0.0196	0.0771
COS	0.0021	0.0021	0.0021	0.0019	0.0019	0.0031
Thiophene	0.0011	0.0023	0.0023	0.0000	0.0000	0.0000
CH_3SH	0.0020	0.0014	0.0014	0.0000	0.0000	0.0014
C_2H_5SH	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001
Ethylene	0.4359	0.2863	0.2863	0.0920	0.6889	0.9867
Ethane	0.6512	0.4518	0.4518	0.0833	1.2203	1.5965
Propylene	0.5319	0.2994	0.2994	0.0249	0.2248	1.1883
Propane	0.1351	0.1051	0.1051	0.0728	0.1038	0.2703
Butylene	-.----	-.----	-.----	-.----	-.----	-.----
Butane	0.0706	0.0389	0.0389	0.0057	0.0256	0.0960
Benzene	0.1072	0.1074	0.1074	0.0000	0.0855	0.0217
Toluene	0.0374	0.0421	0.0421	0.0000	0.0000	0.0000
Methanol	0.0000	0.4532	0.0000	0.4385	3.5977	7.5832

Notes: Due to sampling difficulty, sour gas sample was taken to be the same as PCS exit sample.

TABLE B-5

GAS ANALYSIS SUMMARY FOR GOP-6, AMIP-3 11:15-11:30 SAMPLE TIME

Species	Sample Train	PCS Exit	Sour Gas	Sweet Gas	Flash Gas	Acid Gas
H_2	30.10	30.98	30.64	44.53	20.13	1.2267
CO	15.19	15.53	16.97	23.61	25.22	2.7687
CH_4	7.30	6.80	7.28	6.97	17.09	5.7707
CO_2	28.88	27.45	26.76	0.2073	15.59	64.65
N_2	19.22	17.94	17.05	24.68	20.35	22.09
H_2S	0.0657	0.0562	0.0582	0.0018	0.0214	0.0965
COS	0.0025	0.0024	0.0024	0.0019	0.0019	0.0045
Thiophene	0.0015	0.0011	0.0011	0.0000	0.0000	0.0000
CH_3SH	0.0034	0.0033	0.0033	0.0000	0.0004	0.0027
C_2H_5SH	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CS_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Ethylene	0.5971	0.6094	0.5055	0.0000	0.5933	1.3795
Ethane	0.7212	0.7383	0.6252	0.0000	0.8306	1.8887
Propylene	0.2521	0.2594	0.2154	0.0358	0.0869	0.5195
Propane	0.0941	0.0989	0.0855	0.0127	0.0402	0.2135
Butylene	0.9453	1.0545	0.8667	0.0000	0.1188	1.7519
Butane	0.0310	0.0415	0.0335	0.0000	0.0038	0.0697
Benzene	0.1143	0.1129	0.0863	0.0000	0.0000	0.2273
Toluene	0.0405	0.0516	0.0361	0.0000	0.0000	0.0244
Methanol	0.0000	0.0000	0.0000	0.0000	0.1475	5.5063

APPENDIX C
GASIFIER-PCS SYSTEM
MASS BALANCE RESULTS

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-1 6-17-81 12:00-13:15

REACTOR SPECIFICATIONS

PRESSURE = 101.7 PSIG
TEMPERATURE = 1729.9 DEG.F
BED HEIGHT = 15.0 IN.
BED DIAMETER = 6.0 IN.
ESTIMATED BED VOIDAGE = 0.96
SOLIDS HOLDUP = 0.7 LB

FEED RATES AND RATIOS

PEAT = 37.01 LB/HR
STEAM = 41.59 LB/HR
OXYGEN = 7.32 LB/HR
NITROGEN = 9.22 LB/HR
PURGE N2 = 12.14 LB/HR
H2O/CARBON = 1.70 MOLES H2O/MOLE C
O2/CARBON = 0.17 MOLES O2/MOLE C
N2/O2 = 1.44 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

	MASS	C	H	O	N	S
PEAT	37.0	16.27	1.51	17.65	0.31	0.052
GASES	70.3	0.00	4.65	44.25	21.36	0.000
TOTAL INPUT	107.3	16.27	6.17	61.90	21.67	0.052
CHAR	6.2	3.53	0.09	0.96	0.05	0.006
DUST	2.9	2.05	0.07	0.31	0.04	0.003
GASES	96.8	10.55	6.50	58.11	21.64	0.035
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	106.0	16.12	6.67	59.38	21.73	0.044
% RECOVERY	98.8%	99.1%	108.1%	95.9%	100.3%	83.7%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	64.8
DRY MAKE GAS FLOW RATE (SCFM)	13.4
HEATING VALUE OF SWEET GAS (BTU/SCF)	322.9
EFFLUENT FLOW RATES (LB/HR)	
CO	7.76
H2	1.15
CH4	2.02
CO2	20.91
N2	21.64
H2S	0.035
COS	0.003

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-1 6-17-81 12:00-13:15

REACTOR SPECIFICATIONS

PRESSURE = 802.5 KPA
TEMPERATURE = 943.3 DEG.C
BED HEIGHT = 0.38 METERS
BED DIAMETER = 0.152 METERS
ESTIMATED BED VOIDAGE = 0.96
SOLIDS HOLDUP = 0.3 KG

FEED RATES AND RATIOS

PEAT = 16.79 KG/HR
STEAM = 18.86 KG/HR
OXYGEN = 3.32 KG/HR
NITROGEN = 4.18 KG/HR
PURGE N2 = 5.51 KG/HR
H2O/CARBON = 1.70 MOLES H2O/MOLE C
O2/CARBON = 0.17 MOLES O2/MOLE C
N2/O2 = 1.44 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN KG/HR

	MASS	C	H	O	N	S
PEAT	16.8	7.38	0.69	8.01	0.14	0.024
GASES	31.9	0.00	2.11	20.07	9.69	0.000
TOTAL INPUT	48.7	7.38	2.80	28.08	9.83	0.024
CHAR	2.8	1.60	0.04	0.44	0.02	0.003
DUST	1.3	0.93	0.03	0.14	0.02	0.001
GASES	43.9	4.78	2.95	26.36	9.82	0.016
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	48.1	7.31	3.02	26.93	9.86	0.020
% RECOVERY	98.8%	99.1%	108.1%	95.9%	100.3%	83.7%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	64.8
DRY MAKE GAS FLOW RATE (SCMM)	0.38
HEATING VALUE OF SWEET GAS (KJ/SCM)	12030
EFFLUENT FLOW RATES (KG/HR)	
CO	3.52
H2	0.52
CH4	0.92
CO2	9.48
N2	9.82
H2S	0.016
COS	0.002

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-2 6-25-81 12:15-13:00

REACTOR SPECIFICATIONS

PRESSURE = 104.2 PSIG
TEMPERATURE = 1602.2 DEG.F
BED HEIGHT = 15.0 IN.
BED DIAMETER = 6.0 IN.
ESTIMATED BED VOIDAGE = 0.96
SOLIDS HOLDUP = 0.7 LB

FEED RATES AND RATIOS

PEAT = 68.56 LB/HR
STEAM = 25.27 LB/HR
OXYGEN = 12.35 LB/HR
NITROGEN = 5.34 LB/HR
PURGE N2 = 11.27 LB/HR
H2O/CARBON = 0.57 MOLES H2O/MOLE C
O2/CARBON = 0.16 MOLES O2/MOLE C
N2/O2 = 0.49 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

	MASS	C	H	O	N	S
PEAT	68.6	29.32	2.67	33.27	0.62	0.119
GASES	54.2	0.00	2.83	34.79	16.61	0.000
TOTAL INPUT	122.8	29.32	5.50	68.06	17.23	0.119
CHAR	2.2	1.38	0.02	0.01	0.02	0.002
DUST	0.9	0.64	0.02	0.08	0.01	0.001
GASES	108.4	18.22	7.03	65.63	17.00	0.515
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	111.4	20.24	7.08	65.73	17.02	0.518
% RECOVERY	90.8%	69.0%	128.6%	96.6%	98.8%	435.7%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	62.1
DRY MAKE GAS FLOW RATE (SCFM)	18.3
HEATING VALUE OF SWEET GAS (BTU/SCF)	387.4
EFFLUENT FLOW RATES (LB/HR)	
CO	17.65
H2	1.81
CH4	3.53
CO2	29.35
N2	17.00
H2S	0.548
COS	0.000

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-2 6-25-81 12:15-13:00

REACTOR SPECIFICATIONS

PRESSURE = 819.5 KPA
TEMPERATURE = 872.3 DEG.C
BED HEIGHT = 0.38 METERS
BED DIAMETER = 0.152 METERS
ESTIMATED BED VOIDAGE = 0.96
SOLIDS HOLDUP = 0.3 KG

FEED RATES AND RATIOS

PEAT = 31.10 KG/HR
STEAM = 11.46 KG/HR
OXYGEN = 5.60 KG/HR
NITROGEN = 2.42 KG/HR
PURGE N2 = 5.11 KG/HR
H2O/CARBON = 0.57 MOLES H2O/MOLE C
O2/CARBON = 0.16 MOLES O2/MOLE C
N2/O2 = 0.49 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN KG/HR

	MASS	C	H	O	N	S
PEAT	31.1	13.30	1.21	15.09	0.28	0.054
GASES	24.6	0.00	1.28	15.78	7.53	0.000
TOTAL INPUT	55.7	13.30	2.50	30.87	7.82	0.054
CHAR	1.0	0.63	0.01	0.01	0.01	0.001
DUST	0.4	0.29	0.01	0.04	0.00	0.000
GASES	49.2	8.26	3.19	29.77	7.71	0.234
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	50.5	9.18	3.21	29.81	7.72	0.235
% RECOVERY	90.8%	69.0%	128.6%	96.6%	98.8%	435.7%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	62.1
DRY MAKE GAS FLOW RATE (SCMM)	0.52
HEATING VALUE OF SWEET GAS (KJ/SCM)	14431
EFFLUENT FLOW RATES (KG/HR)	
CO	8.00
H2	0.82
CH4	1.60
CO2	13.31
N2	7.71
H2S	0.248
COS	0.000

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-3 7-15-81 11:00-12:00

REACTOR SPECIFICATIONS

PRESSURE = 104.2 PSIG
TEMPERATURE = 1582.3 DEG.F
BED HEIGHT = 15.0 IN.
BED DIAMETER = 6.0 IN.
ESTIMATED BED VOIDAGE = 0.91
SOLIDS HOLDUP = 1.5 LB

FEED RATES AND RATIOS

PEAT = 57.61 LB/HR
STEAM = 32.44 LB/HR
OXYGEN = 11.55 LB/HR
NITROGEN = 10.25 LB/HR
PURGE N2 = 12.86 LB/HR
H2O/CARBON = 0.84 MOLES H2O/MOLE C
O2/CARBON = 0.17 MOLES O2/MOLE C
N2/O2 = 1.01 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

	MASS	C	H	O	N	S
PEAT	57.6	25.65	2.39	26.40	0.54	0.079
GASES	67.1	0.00	3.63	40.35	23.11	0.000
TOTAL INPUT	124.7	25.65	6.02	66.76	23.65	0.079
CHAR	9.1	4.96	0.36	2.96	0.12	0.034
DUST	3.0	2.03	0.05	0.37	0.04	0.003
GASES	109.3	16.58	6.78	62.30	23.54	0.047
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	121.4	23.58	7.19	65.63	23.70	0.083
% RECOVERY	97.3%	91.9%	119.4%	98.3%	100.2%	105.9%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	64.6
DRY MAKE GAS FLOW RATE (SCFM)	18.6
HEATING VALUE OF SWEET GAS (BTU/SCF)	351.5
EFFLUENT FLOW RATES (LB/HR)	
CO	15.16
H2	1.73
CH4	3.33
CO2	27.79
N2	23.54
H2S	0.047
COS	0.005

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-3 7-15-81 11:00-12:00

REACTOR SPECIFICATIONS

PRESSURE = 819.9 KPA
TEMPERATURE = 861.3 DEG.C
BED HEIGHT = 0.38 METERS
BED DIAMETER = 0.152 METERS
ESTIMATED BED VOIDAGE = 0.91
SOLIDS HOLDUP = 0.7 KG

FEED RATES AND RATIOS

PEAT = 26.13 KG/HR
STEAM = 14.71 KG/HR
OXYGEN = 5.24 KG/HR
NITROGEN = 4.65 KG/HR
PURGE N2 = 5.83 KG/HR
H2O/CARBON = 0.84 MOLES H2O/MOLE C
O2/CARBON = 0.17 MOLES O2/MOLE C
N2/O2 = 1.01 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN KG/HR

	MASS	C	H	O	N	S
PEAT	26.1	11.64	1.08	11.98	0.24	0.036
GASES	30.4	0.00	1.65	18.30	10.48	0.000
TOTAL INPUT	56.6	11.64	2.73	30.28	10.73	0.036
CHAR	4.1	2.25	0.16	1.34	0.06	0.015
DUST	1.4	0.92	0.02	0.17	0.02	0.001
GASES	49.6	7.52	3.08	28.26	10.68	0.021
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	55.0	10.69	3.26	29.77	10.75	0.038
% RECOVERY	97.3%	91.9%	119.4%	98.3%	100.2%	105.9%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	64.6
DRY MAKE GAS FLOW RATE (SCMM)	0.53
HEATING VALUE OF SWEET GAS (KJ/SCM)	13097
EFFLUENT FLOW RATES (KG/HR)	
CO	6.88
H2	0.79
CH4	1.51
CO2	12.60
N2	10.68
H2S	0.021
COS	0.002

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-4B 8-19-81 10:30-11:30

REACTOR SPECIFICATIONS

PRESSURE = 104.7 PSIG
TEMPERATURE = 1606.5 DEG.F
BED HEIGHT = 15.0 IN.
BED DIAMETER = 6.0 IN.
ESTIMATED BED VOIDAGE = 0.96
SOLIDS HOLDUP = 0.7 LB

FEED RATES AND RATIOS

PEAT = 57.86 LB/HR
STEAM = 33.05 LB/HR
OXYGEN = 9.94 LB/HR
NITROGEN = 11.37 LB/HR
PURGE N2 = 9.25 LB/HR
H2O/CARBON = 0.83 MOLES H2O/MOLE C
O2/CARBON = 0.14 MOLES O2/MOLE C
N2/O2 = 1.31 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

	MASS	C	H	O	N	S
PEAT	57.9	26.55	2.51	25.52	0.53	0.084
GASES	63.6	0.00	3.70	39.29	20.63	0.000
TOTAL INPUT	121.5	26.55	6.20	64.81	21.15	0.084
CHAR	10.5	4.14	0.12	2.08	0.07	0.026
DUST	6.9	4.78	0.11	0.67	0.07	0.006
GASES	105.3	15.33	6.56	62.37	21.03	0.042
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	122.7	24.25	6.79	65.11	21.17	0.074
% RECOVERY	101.0%	91.3%	109.5%	100.5%	100.1%	87.2%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	57.7
DRY MAKE GAS FLOW RATE (SCFM)	17.1
HEATING VALUE OF SWEET GAS (BTU/SCF)	326.8
EFFLUENT FLOW RATES (LB/HR)	
CO	12.57
H2	1.65
CH4	2.58
CO2	29.34
N2	21.03
H2S	0.042
COS	0.004

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-4B 8-19-81 10:30-11:30

REACTOR SPECIFICATIONS

PRESSURE = 822.9 KPA
TEMPERATURE = 874.7 DEG.C
BED HEIGHT = 0.38 METERS
BED DIAMETER = 0.152 METERS
ESTIMATED BED VOIDAGE = 0.96
SOLIDS HOLDUP = 0.3 KG

FEED RATES AND RATIOS

PEAT = 26.24 KG/HR
STEAM = 14.99 KG/HR
OXYGEN = 4.51 KG/HR
NITROGEN = 5.16 KG/HR
PURGE N2 = 4.20 KG/HR
H2O/CARBON = 0.83 MOLES H2O/MOLE C
O2/CARBON = 0.14 MOLES O2/MOLE C
N2/O2 = 1.31 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN KG/HR

	MASS	C	H	O	N	S
PEAT	26.2	12.04	1.14	11.58	0.24	0.038
GASES	28.9	0.00	1.68	17.82	9.36	0.000
TOTAL INPUT	55.1	12.04	2.81	29.40	9.59	0.038
CHAR	4.8	1.88	0.05	0.94	0.03	0.012
DUST	3.1	2.17	0.05	0.30	0.03	0.003
GASES	47.8	6.95	2.98	28.29	9.54	0.019
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	55.7	11.00	3.08	29.53	9.60	0.033
% RECOVERY	101.0%	91.3%	109.5%	100.5%	100.1%	87.2%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	57.7
DRY MAKE GAS FLOW RATE (SCMM)	0.48
HEATING VALUE OF SWEET GAS (KJ/SCM)	12175
EFFLUENT FLOW RATES (KG/HR)	
CO	5.70
H2	0.75
CH4	1.17
CO2	13.31
N2	9.54
H2S	0.019
COS	0.002

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-6 9-23-81 10:00-11:30

REACTOR SPECIFICATIONS

PRESSURE = 104.9 PSIG
TEMPERATURE = 1631.5 DEG.F
BED HEIGHT = 20.0 IN.
BED DIAMETER = 6.0 IN.
ESTIMATED BED VOIDAGE = 0.88
SOLIDS HOLDUP = 2.8 LB

FEED RATES AND RATIOS

PEAT = 71.59 LB/HR
STEAM = 35.30 LB/HR
OXYGEN = 13.15 LB/HR
NITROGEN = 5.15 LB/HR
PURGE N2 = 11.04 LB/HR
H2O/CARBON = 0.72 MOLES H2O/MOLE C
O2/CARBON = 0.15 MOLES O2/MOLE C
N2/O2 = 0.45 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN LB/HR

	MASS	C	H	O	N	S
PEAT	71.6	32.51	2.98	31.65	0.75	0.123
GASES	64.6	0.00	3.95	44.50	16.19	0.000
TOTAL INPUT	136.2	32.51	6.93	76.15	16.94	0.123
CHAR	15.5	7.91	0.10	2.87	0.07	0.055
DUST	9.5	6.90	0.17	0.93	0.06	0.009
GASES	111.4	18.61	7.09	68.83	16.80	0.067
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	136.4	33.42	7.36	72.63	16.93	0.131
% RECOVERY	100.1%	102.8%	106.3%	95.4%	99.9%	106.8%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	57.2
DRY MAKE GAS FLOW RATE (SCFM)	18.5
HEATING VALUE OF SWEET GAS (BTU/SCF)	393.2
EFFLUENT FLOW RATES (LB/HR)	
CO	13.26
H2	1.88
CH4	3.65
CO2	37.34
N2	16.80
H2S	0.069
COS	0.005

NCSU DEPARTMENT OF CHEMICAL ENGINEERING

FLUIDIZED BED COAL GASIFICATION REACTOR

RUN GOP-6 9-23-81 10:00-11:30

REACTOR SPECIFICATIONS

PRESSURE = 824.7 KPA
TEMPERATURE = 888.6 DEG.C
BED HEIGHT = 0.51 METERS
BED DIAMETER = 0.152 METERS
ESTIMATED BED VOIDAGE = 0.88
SOLIDS HOLDUP = 1.3 KG

FEED RATES AND RATIOS

PEAT = 32.47 KG/HR
STEAM = 16.01 KG/HR
OXYGEN = 5.97 KG/HR
NITROGEN = 2.34 KG/HR
PURGE N2 = 5.01 KG/HR
H2O/CARBON = 0.72 MOLES H2O/MOLE C
O2/CARBON = 0.15 MOLES O2/MOLE C
N2/O2 = 0.45 MOLES N2/MOLE O2

ELEMENTAL MATERIAL BALANCES : FLOWS IN KG/HR

	MASS	C	H	O	N	S
PEAT	32.5	14.75	1.35	14.36	0.34	0.056
GASES	29.3	0.00	1.79	20.18	7.34	0.000
TOTAL INPUT	61.8	14.75	3.14	34.54	7.69	0.056
CHAR	7.0	3.59	0.05	1.30	0.03	0.025
DUST	4.3	3.13	0.08	0.42	0.03	0.004
GASES	50.5	8.44	3.22	31.22	7.62	0.031
WASTEWATER	0.0	0.00	0.00	0.00	0.00	0.000
TOTAL OUTPUT	61.9	15.16	3.34	32.94	7.68	0.059
% RECOVERY	100.1%	102.8%	106.3%	95.4%	99.9%	106.8%

OUTPUT VARIABLES

CARBON CONVERSION (PERCENT)	57.2
DRY MAKE GAS FLOW RATE (SCMM)	0.52
HEATING VALUE OF SWEET GAS (KJ/SCM)	14648
EFFLUENT FLOW RATES (KG/HR)	
CO	6.01
H2	0.85
CH4	1.66
CO2	16.94
N2	7.62
H2S	0.031
COS	0.002

APPENDIX D
ACID GAS REMOVAL SYSTEM
MASS BALANCE RESULTS

NCSU DEPARTMENT OF CHEMICAL ENGINEERING
ACID GAS REMOVAL SYSTEM

RUN NUMBER GOP4B,AMIP-2
INTEGRATED
DATE 8/19/1981

STREAM COMPOSITION (MOL %)

	SOUR GAS	SWEET GAS	FLASH GAS	STRIP N2	ACID GAS	ABSORB EXIT *	FLASH EXIT *	STRIP EXIT *
CO2	23.260	0.320	23.680	0.000	67.150	4.520	4.438	0.000
H2S	0.048	0.005	0.020	0.000	0.077	0.009	0.009	0.003
COS	0.002	0.002	0.002	0.000	0.003	0.000	0.000	0.000
MEOH	0.000	0.000	0.000	0.000	0.000	94.525	94.930	99.851
H2	28.610	38.470	16.450	0.000	0.888	0.208	0.138	0.078
CO	15.600	20.420	18.940	0.000	1.397	0.192	0.111	0.011
N2	25.750	34.370	28.650	100.000	24.710	0.223	0.101	0.057
CH4	5.550	6.310	9.820	0.000	2.520	0.202	0.161	0.000
C2H4	0.286	0.092	0.689	0.000	0.987	0.043	0.040	0.000
C2H6	0.452	0.083	1.220	0.000	1.597	0.077	0.072	0.000

* CALCULATED

MASS BALANCE (LB-MOLES/HR)

	IN		OUT					
	SOUR GAS	STRIP N2	SWEET GAS	FLASH GAS	ACID GAS	TOTAL IN *	TOTAL OUT *	PERCENT RECOVERY
CO2	0.525	0.000	0.005	0.012	0.555	0.525	0.572	108.90
H2S	0.001	0.000	0.000	0.000	0.001	0.001	0.001	66.71
COS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	120.81
MEOH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
H2	0.646	0.000	0.622	0.008	0.007	0.646	0.638	98.68
CO	0.352	0.000	0.330	0.009	0.012	0.352	0.351	99.67
N2	0.581	0.199	0.556	0.014	0.204	0.780	0.774	99.21
CH4	0.125	0.000	0.102	0.005	0.021	0.125	0.128	101.90
C2H4	0.006	0.000	0.001	0.000	0.008	0.006	0.010	154.43
C2H6	0.010	0.000	0.001	0.001	0.013	0.010	0.015	148.46
TOTAL (LB-MOLES/HR)	2.258	0.199	1.617	0.049	0.827	2.447	2.488	101.7

* METHANOL-FREE BASIS

TOTAL METHANOL LOSS = 0.000 LB-MOLES/HR = 0.000 GALLONS/HR

NCSU DEPARTMENT OF CHEMICAL ENGINEERING
ACID GAS REMOVAL SYSTEM

RUN NUMBER GOP-6,AMIP-3
INTEGRATED
DATE 9/23/1981

STREAM COMPOSITION (MOL %)

	SOUR GAS	SWEET GAS	FLASH GAS	STRIP N2	ACID GAS	ABSORB EXIT *	FLASH EXIT *	STRIP EXIT *
CO2	26.760	0.207	15.590	0.000	64.650	3.808	3.735	0.000
H2S	0.058	0.002	0.021	0.000	0.097	0.008	0.008	0.002
COS	0.002	0.002	0.002	0.000	0.004	0.000	0.000	0.000
MEOH	0.000	0.000	0.147	0.000	5.506	95.055	95.649	99.972
H2	30.640	44.530	20.130	0.000	1.227	0.222	0.097	0.025
CO	16.970	23.610	25.220	0.000	2.769	0.221	0.065	0.000
N2	17.050	24.680	20.350	100.000	22.090	0.133	0.006	0.000
CH4	7.280	6.970	17.090	0.000	5.771	0.390	0.285	0.000
C2H4	0.506	0.000	0.593	0.000	1.380	0.072	0.069	0.000
C2H6	0.625	0.000	0.831	0.000	1.889	0.089	0.085	0.000

* CALCULATED

MASS BALANCE (LB-MOLES/HR)

	IN		OUT					
	SOUR GAS	STRIP N2	SWEET GAS	FLASH GAS	ACID GAS	TOTAL IN *	TOTAL OUT *	PERCENT RECOVERY
CO2	0.607	0.000	0.003	0.015	0.608	0.607	0.627	103.27
H2S	0.001	0.000	0.000	0.000	0.001	0.001	0.001	72.41
COS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	132.95
MEOH	0.000	0.000	0.000	0.000	0.052	0.000	0.000	0.00
H2	0.695	0.000	0.659	0.020	0.012	0.695	0.691	99.45
CO	0.385	0.000	0.350	0.025	0.026	0.385	0.401	104.12
N2	0.387	0.199	0.365	0.020	0.208	0.585	0.593	101.35
CH4	0.165	0.000	0.103	0.017	0.054	0.165	0.174	105.65
C2H4	0.011	0.000	0.000	0.001	0.013	0.011	0.014	118.33
C2H6	0.014	0.000	0.000	0.001	0.018	0.014	0.019	131.14
TOTAL (LB-MOLES/HR)	2.267	0.199	1.481	0.099	0.941	2.464	2.519	102.2

* METHANOL-FREE BASIS

TOTAL METHANOL LOSS = 0.052 LB-MOLES/HR = 0.248 GALLONS/HR